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GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581

CONTRIBUTIONS TO ECONOMIC
GEOLOGY

(SHORT PAPERS AND PRELIMINARY REPORTS)

1913

PART II.—MINERAL FUELS

M. R. CAMPBELL AND DAVID WHITE
GEOLOGISTS IN CHARGE



WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913.

PART II. MINERAL FUELS.

M. R. CAMPBELL and DAVID WHITE, *Geologists in Charge.*

INTRODUCTION.

This volume is the eighth of a series that includes Bulletins 316, 341, 381, 431, 471, 531, 541, and 581, "Contributions to economic geology (Part II)" for 1906, 1907, 1908, 1909, 1910, 1911, 1912, and 1913, respectively. Previous to 1906 the annual "Contributions" consisted of one part only and papers on mineral fuels were included with the papers on metals and nonmetals except fuels in a single volume. These earlier volumes are Bulletins 213, 225, 260, and 285, for 1902, 1903, 1904, and 1905, respectively.

As the subtitle indicates, the papers included are of two classes—(1) short papers giving comparatively detailed descriptions of occurrences that have economic interest but are not of sufficient importance to warrant a more extended description; (2) preliminary reports on economic investigations the results of which are to be published later in more detailed form. These papers are such only as have a direct economic bearing, all topics of purely scientific interest being excluded. They have been grouped according to subjects or general regions and each group has been issued as an advance chapter as soon as it was ready.

Brief abstracts of the Survey's publications of the year are given in the annual report of the Director. The complete list of Survey publications affords, by means of finding lists of subjects and of authors, further aid in ascertaining the extent of the Survey's work in economic geology.

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DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581—A

**OIL SHALE OF NORTHWESTERN COLORADO
AND NORTHEASTERN UTAH**

BY

E. G. WOODRUFF

AND

DAVID T. DAY

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—A



WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

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PETROLEUM AND NATURAL GAS.

OIL SHALE OF NORTHWESTERN COLORADO AND NORTHEASTERN UTAH.

By E. G. WOODRUFF and DAVID T. DAY.

INTRODUCTION.

It has been known for many years that highly bituminous shale, or oil shale, occurs in the Green River formation of the Uinta Basin in Colorado and Utah. Eldridge,¹ who studied the gilsonite veins in this region in 1901, incidentally mentions the shale. He states that the Green River formation includes "shales and limestones, bituminous, locally in a degree to be of economic value." Since the publication of that paper reports have been current from time to time that this shale is rich in petroleum, and that it compares favorably with the Scotch oil shale which has been successfully utilized in the commercial manufacture of petroleum products for half a century.

In order to determine the geographic distribution and thickness of the shale E. G. Woodruff, assisted by W. P. Woodring, carried on in the summer of 1913 a reconnaissance survey of a part of the area occupied by the Green River formation in Utah and Colorado and in collaboration with D. T. Day made field tests to determine the amount of oil and other distillation products that can be obtained from the shale. Later Mr. Day made laboratory tests of some of the same shale and also examined the oil obtained in the field in order to determine its quality and to see if by better methods of distillation its quality could be improved.

The results of the season's work, though not of such a character as to demonstrate the feasibility of immediate utilization of the shale in the production of petroleum, seem to indicate that there is here a large reserve supply of oil, which sooner or later will be used to supplement the product of the well-known oil fields.

The results of the tests and of the areal distribution and character of the shale are here briefly stated in the hope that technologists may be interested in the investigation and may actually prove on the ground whether or not the shale can be utilized at the present time.

¹ Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 219-452, 1901.

THE SHALE.

OCCURRENCE AND CHARACTER.

The areal distribution of the shale has been determined in a general way only. In Utah it extends northward from its line of outcrop, shown in Plate I, toward the interior of the Uinta Basin, but its limits in that direction can only be conjectured because its northward extension is concealed beneath more recently deposited beds, which overlap it unconformably. It is probable, however, that bituminous shale underlies nearly all the deeper parts of the Uinta Basin in this State. In Colorado only the southern edge of the area was examined, but previous geologic work in adjacent areas to the east and north, where the base of the Green River formation has been mapped, indicates that the area containing shale is very similar in shape to that of the outcrop of the Green River formation (see Pl. I, p. 18), though considerably smaller. It is believed that in Utah the greatest depth of the shale below the surface in the center of the basin exceeds 2,000 feet but that in Colorado it is much less.

Bituminous shale occurs in lenticular beds ranging from a fraction of an inch to 80 feet in thickness. A continuous exposure of half a mile or so generally reveals only a moderate amount of variability, but the study of a township shows a great range in thickness and lack of continuity in the lenses. At some places the shale beds are thick and have a fairly uniform content of bitumen throughout, whereas at others the beds are split into many thin members some of which are rich in bitumen while others contain only moderate quantities.

The bituminous shale does not split or break easily but separates readily from the associated beds. This ease of separation from the adjacent material is an important factor in the development of a shale-oil industry, as the shale can thus be readily separated in mining from the other material carrying little or no bitumen.

PHYSICAL PROPERTIES.

The shale is light to dark brown, thin but slightly irregularly bedded, has a velvety luster, and gives when scratched a light-brown streak. When examined under a hand lens the streak is seen to have a vitreous luster, which appears to be produced by a thick fatty substance. In many specimens rich bituminous layers alternate with leaner streaks. These layers are not cleavable one from another, yet one merges sharply into the other; consequently it is difficult to separate the lean and fat shale in laboratory practice and impracticable in commercial processes. The shale is very tough, being split along the bedding planes with difficulty, and it strongly resists breaking across the stratification. When broken it exhibits splintery edges. From hand specimens it is evident that the shale contains considerable

bitumen and when hit with a hammer it gives off a petroleum odor. A sliver inserted in a flame burns with a sooty smoke and gives an odor of burning petroleum. When blocks of the shale are ignited in a pile the pieces soften under the effect of the heat and become about as plastic as hot asphalt paving. Complete combustion leaves only a gray residue, composed mostly of clay, lime, and sand.

The major bedding and a large part of the minor bedding are regular, but in most of the rich shale there is an irregularity of lamination which gives to it a peculiar curly structure like the curling of oak wood about a knot. This structure is so well shown in weathered specimens, as the result of the differential alteration of the fat and lean laminæ, that such material was called in the field "curly shale." The "curly shale" was found to be richer in bitumen than the shale composed of regular and even laminæ. Chemical and microscopic examinations of the shale reveal a most intimate mixture of calcite and small quantities of quartz in fine round grains and clay, embedded in a mass of macerated vegetable débris consisting in part of cells, spores, wood, and pollen grains. Some specimens may show the flowage of oil residue, but this has not been conclusively demonstrated.

The specific gravity of the shale is shown in the following table from tests made by W. T. Schaller:

Specific gravity of bituminous shale.

Kimball Creek.....	1. 63
Do.....	1. 62
Do.....	1. 66
Conn Creek.....	1. 52
Average.....	1. 60

When fresh bituminous shale is exposed to the air it changes to a light brown and finally, on continued exposure, to gray. Weathered samples of the best shale were found to be light gray, whereas less rich ones are darker in color. On account of this change of color from weathering many persons have been misled, thinking that the darker color indicated greater richness than the lighter color. Weathering does not seem to have affected the shale deeply, though there are some indications that the shale under cover is richer than that along the outcrop.

FIELD TESTS.

Field tests were made in a portable still designed by Mr. Day and operations were at first carried on under his immediate supervision. Mr. Day remained in the field until the apparatus was thoroughly tested and then the work was carried on by Mr. Woodruff at various places accessible to the railroad where an abundant supply of the best shale could be procured. The basic principle of the operation was to heat the shale, thus vaporizing the volatile hydrocarbons and destructively distilling the other forms of organic matter present in the shale.

The distillation products were conducted through a pipe to a condensing coil, where the heavier products were liquefied and conducted into receivers and the gases permitted to escape.

The retort into which the shale was charged consisted of a section of 12-inch iron casing pipe 4 feet long, having flanges screwed on the ends and a removable iron plate with asbestos gaskets fitted to each end of the retort. On one side of the retort there was fitted a small steam dome, a pressure gage, and a safety valve. From the top of the dome a pipe led to a block-tin condensing coil in a small water-filled tank. The coil discharged into Wolff bottles set in series and provided with stopcocks so that the liquids could be drawn off without interfering with the operation of the condenser. During the operation the retort was suspended from iron supports in a narrow trench, covered with iron plates and earth, and a flue erected at the back. Heat was obtained from a wood fire placed under the retort.

The operation consisted of removing the head, charging the retort with shale broken into pieces not larger than 4 inches in diameter, and replacing the head. Fire was started to give a gentle heat at first and was gradually increased until the lower part of the retort became red hot; then the fire was held constant until near the close of the process, when it was increased for a short time and then allowed to subside. Water vapor, gas, oil and gas, and finally only gas was the order in which the products were obtained. From seven to eight hours' heating was required for a charge. The liquid products were sealed in cans and shipped to the Washington laboratory. The results of the field tests are as follows:

Results of field distillation of shale.

No. of test.	Locality.	Thick-ness of shale sampled.	Amount of shale used.	Amount of oil obtained.	Amount of oil to the short ton of shale.	Section on p. —
		<i>Ft. in.</i>	<i>Pounds.</i>	<i>Gallons.</i>	<i>Gallons.</i>	
1	Conn Creek.....	1 4	100	3.1	61.2	20
2	Kimball Creek.....	6 0	150	2.4	31.6	15
3	Kimball Creek (second test).....	6 0	156	2	26.2	15
4	Parachute Creek.....	5 10	150	1.5	20.0	12
5	4A ranch.....	5 10	150	.78	10.4	14
6	Temple station.....	4 0	120	2.7	45.2	17
7	Ute station.....	2 0	120	.96	16.0	17
8	White River, subsurface sample.....	3 6	150	2.5	33.3	18
9	White River, sample taken near surface.....	3 6	135	2.4	35.5	18
10	Ninemile Creek.....	6	105	2.1	39.0	19
11	Hill Creek.....	9	135	1.3	16.0	19

From the table given above it will be seen that the amount of oil obtained in the various tests ranged from 10.4 gallons to the ton in test No. 5 to 61.2 gallons in test No. 1, the average for the entire series being 30.4 gallons. The commercial utilization of the shale as a source of petroleum depends upon the quality of the oil produced

and the amount and accessibility of the shale. The quality of the oil obtained in the field tests was determined by Mr. Day in the Survey laboratory at Washington and the results of his examinations are given later, together with a brief discussion of ways and means of improving results. With regard to the amount of shale, the evidence at hand is not so conclusive. The thickness of the bed of shale at the point sampled is given in the table. Some of the beds that were tested are too thin to be profitably mined under present conditions, but they were sampled because of the richness of the shale which they contained. If the beds less than 3 feet in thickness are disregarded the yield will run from 10.4 gallons in sample No. 5 to 35.5 gallons in sample No. 9, the average being 22.5 gallons to the ton of shale. As this average will compare favorably with the yield of the Scotch oil shale, it seems probable that the shale of Utah and Colorado may at the lowest estimate equal in value that of the well-known shale of Scotland from which petroleum has been successfully manufactured for a long time. However, the full extent of the geographic distribution of the shale and its petroleum content have not been adequately determined and much additional field work must be done before these facts can be fully and satisfactorily known.

LABORATORY TESTS.

GENERAL CHECKING TESTS.

Method of the work.—As a check on the field work and also for the purpose of making tests which required special apparatus, samples of shale were distilled under the supervision of Mr. Day. The laboratory tests included distilling the shale in a regular distilling flask, using 100 grams for a charge. The flasks were heated electrically in the usual way and it was found possible to continue the heating until the glass melted. It was found also that when this stage had been reached practically all the volatile matter had been distilled from the shale, leaving a crumbling dry coke. The gases given off were collected and also the ammonia water. The percentage of ammonia was determined in the general chemical laboratory. Analyses of the gases are appended.

Care was taken in condensing the vapor from the distillation to use ice water in the condenser and this is probably the reason why slightly larger yields were obtained than in the field tests.

In selecting material for distillation the entire sample was picked over for average specimens, a large number of these were crushed down and thoroughly mixed, and the sample for examination was taken from this mixture.

Test of shale from "asphalt mine," Conn Creek, Colo., in sec. 1, T. 7 S., R. 98 W. sixth principal meridian.—A sample containing 100

grams of the shale from Conn Creek was heated for a period of about 6 hours. As soon as the shale was sufficiently hot to give off moisture the evolution of gas began. This evolution became more rapid and an especially large volume of gas was given off during the last period of the distillation. The gas was collected over water in half-gallon bottles and sealed for analysis. The bottles were numbered in order that the gas from each stage of the process could be examined separately.

The following yield of products was obtained from the distillation: Crude oil, 24.5 cubic centimeters; fixed gas, 10 liters; ammonia, 0.13 gram, equivalent to 1.02 grams of ammonium sulphate, or 22.5 pounds of ammonium sulphate to the ton of shale; specific gravity of oil, 0.90. The yield of oil to the ton of shale was 68 gallons.

Analyses of gases.—Examination of the gases from two of the distillations gave the following results, the ordinary Orsatt apparatus being used:

Analyses of gases collected in two shale distillations.

Distillation No. 2.

	Percentage composition.					Total.
	Carbon dioxide.	Oxygen.	Carbon monoxide.	Unsaturated hydrocarbons.	Other hydrocarbons and nitrogen.	
Bottle No. 1.....	12.70	1.56	1.56	11.10	73.08	100.00
Bottle No. 2.....	5.20	1.50	7.50	9.50	76.30	100.00
Bottle No. 3.....	3.20	2.00	6.00	10.00	78.80	100.00
Bottle No. 4.....	4.00	1.00	1.60	12.40	81.00	100.00
Bottle No. 5.....	12.40	.60	9.60	6.40	71.00	100.00

Distillation No. 3.

Bottle No. 1.....	19.0	0.5	0.3	0.3	79.9	100.00
Bottle No. 2.....	5.1	1.8	3.1	4.0	86.0	100.00
Bottle No. 3.....	2.0	None.	1.1	4.0	92.9	100.00

On repeating the distillation there was practically no change in yield or character of products. On account of the evolution of carbon dioxide in the latter part of the process, the shale itself was examined and found to be a mixture of true clay shale and a large percentage of calcite. It is evident, therefore, that much of the gas evolved last came from the dissociation of the calcium carbonate. At the highest temperatures some of this carbon dioxide was reduced by the coke to carbon monoxide.

RESULTS OF LEACHING WITH ETHER AND BENZOL.

Much of the bituminous material in the shale occurs in the form of liquid oil and semisolid and solid asphalt, as shown by the extraction with ether and with benzol. By extraction with ether oil to

the extent of 6.2 per cent by weight of the shale was obtained. By reextracting with benzol an additional 6 per cent was obtained, showing that 12.2 per cent of the total weight of the shale existed in the form of oil and asphalt. Thus at least half of the oil and asphalt obtained existed in the shale and is not formed by destructive distillation. When this oil is redistilled it undergoes further destructive distillation as well as fractionation, yielding oils having the usual gradations in gravity.

The odor of the oils distilled from the shale suggested phenol so strongly that some finely divided shale was boiled with 10 per cent solution of caustic soda, and the mixture, after acidifying, was shaken up with ether. By this means about 1 per cent of the total oil was found to consist of substances of the phenol class.

Qualitative tests showed the presence of pyridine compounds easily extracted from shale oil by dilute acids.

Experiments show that the bitumen existing in the shale is only very slightly soluble in methyl alcohol, but after boiling the finely divided shale with dilute hydrochloric or sulphuric acid, it was found that a much greater proportion of the shale was soluble in methyl alcohol, a fact which was confirmed by repetition.

EXAMINATION OF THE SHALE OILS DISTILLED IN THE FIELD.

For purpose of comparison the oils obtained by the field tests were distilled in Engler's distilling bulbs exactly according to the standard method of comparing crude petroleum, with the following results:

Results of distillation by standard method of the oils obtained in the field tests.

Serial No.	Location.	Physical properties.		
		Gravity at 60° F.		Color.
		Specific gravity.	Degrees Baumé.	
1	Kimball Creek	0.9302	20.5	Dark brown.
		a. 8950	26.5	Dark red.
2	Parachute Creek	.9271	21	Dark brown.
		a. 8805	29	Dark red.
3	Conn Creek, No. 1	.9103	24	Dark brown.
		a. 8695	31	Red.
4	Conn Creek, No. 2	.9550	17	Dark brown.
		a. 9060	24.5	Dark red.
5	4A ranch	.9369	19.5	Dark brown.
		(a)		Red.
6	Tunnel on Whisky Creek	.9537	16.8	Dark brown.
7	Tank at tunnel on Whisky Creek	.9550	17	Blackish brown.
		.9550	16.75	Brownish black.
8	Shale from Whisky Creek	(a)		Red.

a After treatment with sulphuric acid.

Results of distillation by standard method of the oils obtained in the field tests—Contd.

Serial No.	Location.	Distillation by Engler's method, by volume.								Unsaturated hydrocarbons (per cent).		Paraffin (per cent).	Asphalt (per cent).
		Begins to boil.	To 150° C.			150°-300° C.		Residuum.		Crude.	150°-300° C.		
		* C.	C. c.	Sp. gr.	C. c.	Sp. gr.	C. c.	Sp. gr.					
1	Kimball Creek	70	5	0.8020	54	0.8874	41.5	0.9649	66.8	64	.....	2.210	
		60	6	.8700	48	.8708	44.0	.9250	.....	50	1.50	.....	
2	Parachute Creek	75	2	.....	48	.8646	50.5	.9437	91.6	45	.....	1.907	
		80	5	.8020	44	.8508	.....	.9100	.....	55	4.60	.....	
3	Conn Creek, No. 1.	70	4	.7745	42	.8519	53.4	.9085	75.6	44	.....	.745	
		80	2	.....	38	.8373	.....	.8928	.....	.....	3.13	.....	
4	Conn Creek, No. 2.	70	7	.8205	53	.8889	.....	.....	72.4	57	.....	9.654	
		70	10	.....	55	.8585	.....	.....	.....	.....	.....	.....	
5	4A ranch	70	5	.7995	51	.8804	44.9	.9605	71.2	56	.....	4.610	
		70	6	.8355	38	.8783	.....	.....	.....	.....	.....	.....	
6	Tunnel on Whiskey Creek.	220	.....	.....	35	.9116	65.9	.9550	69.6	.....	.....	None.	
7	Tank at tunnel on Whiskey Creek.	220	.....	.....	33	.9125	.....	.....	36.0	.....	.....	.....	
8	Shale from Whiskey Creek.	70	5	.8330	45	.8935	.....	.....	76.8	51	.....	.....	
		70	6	.8355	44	.8813	.....	.....	.....	6.00	.....	.....	

HYDROGENATION OF SHALE OILS.

The shale oils obtained in Scotland and elsewhere and those obtained in the present series of distillations are characterized by a large proportion of unsaturated hydrocarbons, involving a considerable loss when these oils are refined. In refining them it is not necessary to remove all these unsaturated hydrocarbons but only those which prevent the manufacture of comparatively colorless and odorless oils by the usual refining process. The proportion of these compounds differs greatly in shales from different parts of the world.

In the distillation of the shale under consideration it is evident that when the process is carried on at the lowest possible temperature the quality of the oil obtained is considerably better.

The success which has lately attended the addition of hydrogen to unsaturated oils, by passing the vapors of the oils and hydrogen together through a porous substance acting as a catalyzer, has been sufficient to justify the treatment of these oils in the same way.

Accordingly a sample of 4.49 kilograms of shale from Temple station, Utah, was distilled under a pressure of 70 to 80 pounds, in an atmosphere of hydrogen. The still contained a coil of tubes filled with a catalyzer consisting of finely divided nickel with a small proportion of palladium (10 ounces of palladium to the ton of nickel). The catalyzer remained at the same temperature as the still. The vapor of the oil and the hydrogen passed together through the catalyzer before leaving the still. The distillation proceeded according to the following table.

Distillation of shale from Temple station, Utah, adding hydrogen under pressure.

[Charge, 4,490 grams in pressure still; continuous coil containing hydrogen with palladiumized nickel as a catalyzer. Residue, 2,850 grams of coke.]

Cut.	Amount of oil obtained (c. c.).	Gravity (°B.).	Temperature (°F.).	Pressure (pounds)
First.....	29	35.2	750-800	80
Second.....	20	33.2	750-800	80
Third.....	60	36.1	750-800	80
Fourth.....	63	38.1	750-800	80
Fifth.....	77	39.7	750-800	70
Sixth.....	44	35.1	750-800	70
Seventh.....	49	33.5	750-800	70
a Average.				
Eighth.....	342	a 36.0		
Ninth.....	80	25.9	750	70
Tenth.....	137	28.7	750-850	None.
Eleventh.....	175	26.7	800-925	None.
	180	24.4	900-1,000	None.

a Average.

First seven cuts steam stillled.

[Charge, 320 cubic centimeters.]

Cut.	Amount of oil obtained (c. c.).	Gravity (°B.).
First.....	25	63.2
Second.....	27.5	55.7
Third.....	20.5	50.0
Residue.....	165	26.1

These shale oils under ordinary redistillation yield oils ranging from 17° to 24° Baumé, whereas in the hydrogen distillation under pressure they ranged from 24.4° to 39.7° Baumé.

Further, when the first seven cuts were redistilled with steam the results showed a large yield of naphtha suitable for all purposes for which gasoline is used. The steam-stilled distillate, when treated with dilute caustic soda, had a marked odor of pyridine, which was easily removed with dilute sulphuric acid. The steam-stilled material required no treatment with acid to render it comparable with the other market grades of naphtha or gasoline. A similar distillation of shale from Parachute Creek, Colo., gave corresponding results, as shown in the table below, but was not completed on account of the accidental leakage of the still.

Distillation of shale from Parachute Creek, Colo., adding hydrogen under pressure.

[Charge, 4,200 grams in pressure still; continuous coil containing hydrogen with charcoal as a catalyzer. Pressure was also carried on condenser.]

Cut.	Volume of oil (c. c.).	Gravity (°B.).	Temperature (°F.).	Pressure (pounds).
First.....	115	35.4	750	70
Second.....	125	28.6	750	70
Third.....	20	25.0	750-850	70-30
Fourth.....	70	25.3	800	None.
Fifth.....	45	23.2	800-1,000	None.

EXTENT OF THE FIELD.

As shown on Plate I (p. 18) bituminous shale extends westward from Rifle, Colo., for a distance of 50 miles and in Utah from the east line of the State for a distance of 75 miles. In the two States there is a total direct east-west distance between extremities of outcrop of 125 miles, but owing to the sinuosities the total line of outcrop is probably twice as great. The extent of shale back of the outcrop has not been determined because neither the nature of the work nor the time and facilities available for it permitted such determination. However, the limits of the Green River formation, which contains the shale, are shown on the map (Pl. I). In Colorado the shale-bearing area is much less extensive than the formation but probably includes as much as 20 townships, whereas in Utah a much greater area contains the shale though most of it is too thin and covered too deeply to be worthy of economic consideration. In considering the areal extent of the shale it should be noted that the Colorado area is probably encircled by a belt of the shale outcrop, whereas in Utah the outcrop of the shale is along the southern side only, the northern being buried beneath younger overlapping formations. In this State shale is known to occur in Strawberry Valley west of Indian Creek (see Pl. I), but probably it is too thin to be considered economically.

SURFACE FEATURES AND CLIMATE.

Westward from Rifle, Colo., for 170 miles, to the vicinity of Colton, Utah, extend the high, steep, and locally precipitous Book Cliffs and Roan Cliffs, which rise 1,000 to 3,000 feet from a rather uneven lowland on the south to the high plateaus on the north. The cliffs do not form a continuous wall but are cut by many streams into a most intricate system of narrow steep-sided valleys between narrow spurs with precipitous sides. These cliffs are so high and so steep that an ascent has been found for a railroad at only one place and by a most tortuous narrow-gage route. Wagon roads cross the cliffs at a few favored spots, and difficult foot trails at fairly short intervals. From the crest of the cliffs a plateau slopes gently northward toward the interior of the Uinta Basin, through which flow White, Green, and Duchesne rivers. The surface of the plateau is cut into a most intricate system of badlands by branches of the streams which rise near the crest of the cliffs and flow northward to the rivers. The bituminous shale underlies the plateau and outcrops along its southern edge.

The region is semiarid—in fact, it is sometimes called a desert. Springs and brooks are common north of the crest of the cliffs, but generally the flow is so small that the water is lost by evaporation or seepage before it has gone far. A few perennial streams have a small flow of water, which is generally so alkaline, except near the source, that it is unsuited for the use of either man or animal. The vegetation consists of pines, cedars, and aspen in the higher parts

of the plateau and of sagebrush and an extremely scanty growth of grass over the greater part of the area.

GEOLOGY.

The geology of the region was studied by Mr. Woodruff only in a general way at a few places along the southern exposures of the bituminous shale and to some extent back of the outcrop in Utah. These examinations, together with reports of previous workers in the field, furnish the data upon which the description of the geology is based.¹ Good exposures of the strata and the distinctive lithology of the rocks render geologic study simple and the results certain. Only general stratigraphic relations will be considered, except in so far as the data relate to the Green River formation, which will be described in detail because that formation contains the bituminous shale to which this report relates.

STRATIGRAPHY.

FORMATIONS PRESENT.

In western Colorado and eastern Utah the igneous basement is covered by a series of Paleozoic, Mesozoic, and Cenozoic formations many thousand feet thick. Among the last to be deposited were the Tertiary rocks, which in part are classified as follows:

Stratigraphic relations of the Green River formation to other Eocene formations in northwestern Colorado and northeastern Utah.

Formation.	Member.	Description.	Thickness.
Bridger formation.		Sandstone, very sandy shale, clay shale, and a few conglomerate beds; prevailing colors pink, brown, and gray. The Bridger is composed of loosely cemented rocks which weather into badland forms. Very irregular bedding is prevalent. Distinguished from the formation above by the slightly greater percentage of shale and by the fossils.	Feet. 600-1,000
Green River formation.	Upper.	Sandstone, very sandy shale, and some clay shale; prevailing colors brown and gray. The sandstone occurs in thick beds and locally contains fossil leaves. Generally even bedded, though not markedly so in central Utah.	500 (Estimated.)
	Middle.	Shale, thin bedded, some of it bituminous; thin beds of calcareous sandstone; prevailing colors, brown, gray, or faint green. This member is remarkable for its uniform thin bedding and for the large amount of bituminous matter which some of the beds contain. (Detailed sections are presented on pp. 13-20.)	100-700
	Lower.	Sandstone, shale, and oolite. The sandstone occurs in beds 1 to 15 feet thick. The shale is sandy, locally calcareous or bituminous, and very even bedded; prevailing colors brown, gray, or faint green. (A detailed section is presented on pp. 14-15.)	1,000-1,425
Wasatch formation.		Shale, generally very sandy, and sandstone. Colors variegated, red, maroon, pink, yellow, brown, and gray. Very irregularly deposited.	1,000-4,000

¹ Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, 1910; Geology of the Rangely oil district, Colo.: U. S. Geol. Survey Bull. 350, 1908. Peale, A. C., Geological report on the Grand River district: U. S. Geol. and Geog. Survey Terr., Tenth Ann. Rept., 1878. Eldridge, G. H., Asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, 1901. Richardson, G. B., Reconnaissance of the Book Cliffs coal field between Grand River, Colo., and Sunnyside, Utah: U. S. Geol. Survey Bull. 371, 1909. Woodruff, E. G., Geology and petroleum resources of the De Beque oil field, Colo.: U. S. Geol. Survey Bull. 531c, pp. 54-68, 1913.

GREEN RIVER FORMATION.

As the study of the oil shale involved the Green River formation only, the other formations were not given much attention. Consideration was given not only to the composition of the formation, but also to the character of the country and to the accessibility of the outcrops. Gale¹ has aptly said: "The valleys and lowland ridges commonly formed in the Wasatch clays are generally bordered by escarpment ridges of more resistant beds that overlie them. This escarpment-forming group of strata is known as the Green River formation." The cliff-forming feature of the Green River is the characteristic which first attracts attention to the formation, especially along the southern margin of the Colorado-Utah area. Closer inspection, however, reveals the even and generally thin bedding of the shale, the bitumen in some of the shale, and the calcareous character of the sandstone and oolite. Generally the oolite is composed of spherules less than one-eighth inch in diameter, but not uncommonly the rock is a pisolite whose spherules are as much as three-fourths inch in diameter. Ripple-marked sandstone beds occur in the lower and middle parts of the formation. Fish scales are common, and even fish remains occur at many places. Excellently preserved insects were obtained at one place and some imperfect specimens at another place. Some fossil turtles were also found.

Work was concentrated on that part of the section carrying the oil shale, and several sections were studied and measured in considerable detail. These sections, which are given below, afford a good idea of the distribution of the shale in the formation and some idea of its comparative richness.

After most of the distillation tests had been made and the richness of certain kinds of shale had been determined it was found possible to estimate very closely the oil content of any given bed, provided it was clearly exposed. The probable limit of error in such estimates is thought to be less than 20 per cent. Accordingly, in measuring the detailed sections at various places many such estimates were made, and they are given in their appropriate places in the sections.

¹ Gale, H. S., Coal fields of northwestern Colorado and northeastern Utah: U. S. Geol. Survey Bull. 415, p. 83, 1910.

Section of part of the middle member of the Green River formation exposed on Parachute Creek, Colo., in sec. 29, T. 5 S., R. 95 W., sixth principal meridian.¹

	Ft.	in.
Shale, brown, carbonaceous, thin bedded.		
Shale, brown, bituminous; weathers cavernous (estimated to contain 20 gallons of crude oil to the ton).....	31	0
Shale, brown, thin bedded, slightly bituminous.....	5	3
Shale, bituminous.....	7	3
Shale, fissile; contains some seams of bituminous shale.....	2	9
Shale, brown.....		5
Shale, bituminous.....	1	0
Shale, thin bedded, slightly bituminous.....		9
Shale, bituminous.....		3
Shale, thin bedded, slightly bituminous.....		9
Shale, brown, fine grained, bituminous; estimated.....	10	0
Shale, brown, thin bedded.....	26	6
Shale, brown, bituminous (estimated to contain 20 gallons of oil to the ton).....	4	10
Shale, brown, thin bedded, fine grained.....	2	6
Shale, brown, slightly bituminous.....	5	0
Shale, fissile, fine grained, thin bedded.....	6	6
Shale, bituminous (sample No. 4, p. 4, obtained from this bed)...	5	10
Shale, brown, thin bedded, slightly carbonaceous, moderately calcareous.		
	110	7

Section along Mount Logan trail, Colo., sec. 26, T. 7 S., R. 97 W.

Base of upper member of Green River formation:

Soil on plateau overlying very sandy brown shale.

Middle member of Green River formation:

	Ft.	in.
Shale, bituminous, "curly".....	11	0
Shale, very light brown.....	130	0
Shale, bituminous, "curly".....	2	3
Shale, moderately bituminous, bitumen evenly distributed throughout the ledge (estimated to contain 20 gallons of oil to the ton).....	81	0
Shale, bituminous.....		10
Shale, brown, slightly carbonaceous.....	79	0
Shale, bituminous.....		13
Shale, brown, slightly bituminous.....	4	5
Shale, bituminous.....		8
Shale, brown.....	2	6
Shale, bituminous.....		8
Shale, brown, slightly bituminous.....	12	0
Shale, bituminous.....		7
Shale, brown, slightly bituminous.....	3	9
Sandstone.....		3
Shale, brown.....		4
Sandstone, brown.....		4
Shale, brown, slightly bituminous.....		6

¹ At this place the exposure occurs in a cliff which is so precipitous that the complete section can not be studied in detail. The section is believed to be typical of strata for 200 feet above the portion presented.

Middle member of Green River formation—Continued.		Ft.	in.
Shale, bituminous.....			5
Shale, brown, slightly bituminous.....	1	2	
Shale, bituminous.....			8
Shale, brown, fissile.....			8
Shale, bituminous.....	1	0	
Shale, brown, slightly bituminous.....	3	2	
Shale, bituminous (estimated to contain 20 gallons of oil to the ton).....	1	1	
Shale, brown, slightly bituminous.....	2	10	
Sandstone, brown.....			8
Shale, brown, slightly bituminous.....	3	4	
Shale, bituminous (estimated to contain 30 gallons of oil to the ton).....			8
Shale, brown, slightly bituminous.....	3	2	
Shale, brown, bituminous.....	9	8	
Shale, brown.....	2	6	
Shale, bituminous (estimated to contain 25 gallons of oil to the ton).....	2	6	
Shale, brown, slightly carbonaceous.....	1	5	
Shale, bituminous (estimated to contain 30 gallons of oil to the ton).....			9
Shale, brown, slightly bituminous.....	2	6	
Shale, bituminous.....	1	0	
Shale, brown, slightly bituminous.....	5	0	
Shale, bituminous (estimated to contain 20 gallons of oil to the ton).....	5	6	
Lower member of Green River formation:			
Shale, gray, thin bedded.....	122	0	
Sandstone, gray.....	2	0	
Shale, gray, fine grained, thin, even bedded; this member seems to be uniform throughout.....	329	0	
Shale, brown, fissile, weathers in flakes as thin as $\frac{1}{16}$ inch....	2	6	
Shale, drab, fine grained, fissile.....	178	0	
Sandstone, tan.....			6
Shale, drab, thin bedded; contains thin layers of shaly sandstone.....	69	0	
Sandstone, tan.....			6
Shale, drab, thin bedded.....	18	0	
Sandstone, tan, slightly irregular in thickness.....	1	6	
Shale, drab, thin bedded.....	28	0	
Sandstone, shaly in lower half.....	4	0	
Shale, thin bedded; this member is uniform throughout except that at intervals of 10 to 20 feet beds of shaly sandstone occur as much as 6 inches thick.....	174	0	
Sandstone, coarse, oolitic.....	1	6	
Sandstone, fine grained, oolitic.....	1	6	
Shale, drab, fissile.....	63	0	
Sandstone, gray.....	6	0	
Shale, gray in upper part, brown in lower, fine grained, fissile.....	147	0	
Shale and sandstone; this member is composed of layers of tan sandy shale and shaly sandstone 6 inches to 2 feet thick.....	92	0	

Lower member of Green River formation—Continued.		Ft.	in.
Sandstone, thick bedded, coarse grained.....		15	0
Shale, tan, very sandy, with many layers of shaly sandstone some of which are as much as 6 inches thick.....		98	0
Sandstone, tan, thick bedded.....		5	0
Shale, tan, sandy; contains layers of shaly sandstone.....		68	0
Shale, red (top of Wasatch formation).			
		1,806	10

Section of part of the bituminous shale exposed at 4A ranch, Colo., in sec. 21, T. 6 S., R. 99 W.¹

	Ft.	in.
Shale, bituminous (estimated to contain 20 gallons of oil to the ton).....	5	3
Shale.....		6
Shale, bituminous, "curly".....		6
Shale.....	1	10
Shale, bituminous, "curly".....		8
Shale.....	4	10
Shale, bituminous.....		8
Shale, carbonaceous, fissile.....	2	10
Shale, bituminous (estimated to contain 25 gallons of oil to the ton).....	1	2
Shale, fissile.....	1	2
Shale, bituminous (estimated to contain 25 gallons of oil to the ton).....		4
Shale, brown, carbonaceous.....		4
	19	9

Section of part of the middle member of Green River formation on north side of Kimball Creek, sec. 5, T. 7 N., R. 100 W.²

	Feet.
Soil and rock débris.....	
Shale, bituminous (samples Nos. 2 and 3, p. 4, were taken from 6 feet of this bed from 12 to 18 feet below the top; the upper half of this bed is believed to be slightly richer than the lower half).....	48
Shale, locally very calcareous.....	35
Shale, bituminous.....	3
Shale, brown, carbonaceous.....	
	86

Section of part of Green River formation exposed at Oil tunnel on Whisky Creek, Colo., in sec. 18, T. 5 S., R. 103 W. (approximate location).

Lower member of Green River formation:		Ft.	in.
Shale, tan, fissile.....			8
Shale, bituminous (same bed as that from which sample No. 8 was obtained; see p. 18.).....			4
Shale, tan, fissile.....		2	0
Shale, tan, sandy.....		9	0
Sandstone, oolitic.....		5	0

¹ This section includes only the lower part of the middle member of the Green River formation; 200 feet of similar strata overlie it.

² This location is given by a resident of the region who is familiar with the land subdivisions. The writers are inclined to think that the location is in error and that the true location is a few miles east of that given.

Lower member of Green River formation—Continued.		Ft.	in.
Shale, tan, sandy.....		40	0
Sandstone, oolitic.....		1	0
Shale, sandy.....		4	0
Sandstone, oolitic, shaly.....		2	0
Shale, tan, sandy; shale, brown, carbonaceous, and oolitic sandstone, in beds from 6 inches to 1 foot thick.....		53	0
Sandstone, oolitic.....		3	6
Shale, tan.....		22	0
Covered by talus.....		21	0
Sandstone, oolitic.....		6	0
Wasatch formation:			
Shale, tan, sandy.....		43	0
Sandstone, gray, very porous, petroliferous.....		13	0
Shale.....			
		225	6

Section of lower part of Green River formation at Black Dragon mine, Dragon, Utah.

Soil.	Ft.	in.
Oolite, buff, coarse.....	6	6
Shale, containing thin beds of sandstone.....	57	0
Oolite, brown.....	21	0
Shale, gray.....	5	4
Sandstone, buff.....	13	0
Shale, gray.....	16	0
Oolite, fine grained.....	5	4
Shale and sandstone.....	21	0
Oolite, coarse grained.....	7	2
Shale and sandstone.....	17	0
Oolite, coarse grained.....	3	8
Sandstone, buff.....	4	2
Shale, gray, fine grained.....	17	0
Oolite, fine grained.....	1	2
Sandstone, buff, fine grained, weathers cavernous.....	4	3
Oolite, coarse grained.....	5	8
Sandstone, buff.....	50	0
Shale, green, weathers brown.....	5	0
Oolite, buff, coarse grained.....	4	0
Sandstone, buff.....	8	2
Shale, faint green.....	4	5
Sandstone, light brown.....	1	0
Shale, gray, weathers cavernous in upper part.....	6	9
Sandstone, buff, massive, with small lenses of shale intercalated in the sandstone.....	59	0
Shale, gray, fine grained.....	12	4
Oolite, buff, coarse grained.....	26	0
Sandstone, buff, weathers cavernous.....	22	0
Shale, green, fine grained.....	3	
Sandstone, yellowish; brown below, gray above; massive; weathers cavernous.....	18	9
Shale, greenish gray, fine grained; this bed is lenticular.....	14	0
Sandstone, chocolate-brown, thick bedded.....	13	6
Shale, green, with brown streaks, fine grained, thin lenticular bedding.....	1	9

	Ft.	in.
Sandstone, light brown, fine grained, in part argillaceous.....	10	9
Shale, green, fine grained.....	1	7
Shale, sandy.....	2	5
Shale, greenish gray, weathers nodular.....	1	0
Sandstone, dark reddish brown.....	1	0
Shale, reddish brown, sandy, thin bedded.....	1	7
Sandstone, reddish brown, fine grained.....	1	4
Shale, greenish gray, fine grained, weathers nodular.....	2	0
Sandstone, reddish brown, argillaceous.....	2	9
Shale, gray, thin bedded.....	1	5
Sandstone, reddish brown, fine grained, cross-bedded.....		6
Shale, gray, fine grained.....	2	7
Sandstone, yellowish brown.....	2	2
Shale, gray, somewhat arenaceous.....		6
Sandstone, reddish brown.....		9
Shale, gray.....		2
Sandstone, dark brown.....		2
Shale, gray, sandy in lower part.....	2	0
Sandstone, brown, fine grained.....		6
Shale, gray, sandy.....		4
Sandstone, brown, fine grained.....		7
Shale, thin bedded.....	1	6
Sandstone, brown, fine grained, lenticular.....	2	7
Shale, gray, very sandy.....	2	2
Sandstone, brown, fine grained; contains lenses of shale.....	3	4
Shale, gray, fine grained, thin bedded.....		3
Sandstone, brown, fine grained.....	3	1
Shale, gray, locally very sandy.....	8	0
Sandstone, light brown, thick bedded.....	12	0
Shale, gray, thin bedded, lenticular.....		5
Sandstone, light brown, fine grained.....	7	9
Alluvium.....		
	529	4

Section on east side of Evacuation Creek, at Ute station on Uintah Railway, Utah.

Sandstone, brown, calcareous; weathers brown; base of upper member of Green River formation.....	Ft.	in.
Shale, brown, thin bedded.....	11	0
Limestone, gray, thin bedded.....	36	0
Shale, gray, calcareous.....	18	0
Limestone, gray, thin bedded.....	6	0
Shale, brown, thin bedded, slightly bituminous (possibly contains 2 or 3 gallons of oil to the ton).....	165	0
Shale, brown, bituminous.....		6
Shale, brown, carbonaceous.....	3	6
Shale, brown, slightly bituminous.....	1	2
Shale, brown, carbonaceous.....	3	4
Shale, brown, bituminous.....		5
Shale, brown, fissile, carbonaceous.....		5
Shale, brown, bituminous.....		3
Shale, brown, carbonaceous; weathers gray.....	62	0
Shale, brown, bituminous.....		8
Shale, brown; carbonaceous; weathers gray.....	1	4

	Ft.	in.
Shale, bituminous.....	1	3
Shale, brown, carbonaceous, thin bedded; weathers gray.....	12	0
Shale, brown, bituminous.....		6
Shale, brown, weathers gray, carbonaceous, with seams of bituminous shale half an inch thick in the lower part.....	5	0
Shale, brown, bituminous.....	1	10
Shale, brown, carbonaceous.....	12	0
Shale, brown, bituminous; somewhat variable in bitumen content (sample No. 6, p. 4, collected at Temple station, represents 4 feet of the lower part of this bed).....	22	6
Shale, brown, carbonaceous; contains some layers of bituminous shale 1 inch thick.....	18	6
Sandstone, brown.....	1	0
Shale, brown, fissile.....	12	0
Limestone, brown.....	1	0
Shale, brown, fissile.....	12	6
Shale, brown, bituminous.....		8
Shale, brown; weathers tan; fine grained, thin bedded; contains fossil insects.....	20	0
Shale, brown, bituminous.....		6
Shale, brown; weathers gray; carbonaceous, very fissile.....	13	0
Shale, rusty brown, very sandy, calcareous.....	40	0
Shale, light tan; weathers gray; calcareous.....	40	0
Sandstone, gray; weathers rusty; thin bedded in lower two-thirds, thick bedded in upper one-third, locally cross-bedded and ripple marked.....	68	0
Shale, light brown, in layers as thin as 0.1 inch, slightly carbonaceous; 45 feet above base occurs a bituminous shale seam 4 inches thick and another of equal thickness 6 feet higher..	58	0
Shale, bituminous.....		1
Shale, brown, carbonaceous.....	1	3
Shale, brown, bituminous ¹		1
Shale, brown, carbonaceous.....		8
Shale, brown, bituminous ¹		1
Shale, brown, carbonaceous.....		6
Shale, brown, bituminous ¹		2
Shale, brown, carbonaceous.....		11
Shale, brown, bituminous ¹		2
Shale, brown, carbonaceous.....		2
Shale, brown, bituminous ¹		2
Shale, brown, locally slightly bituminous.....	28	0
Shale, brown, bituminous.....	1	11
Shale, gray, very calcareous.....	4	0
Shale, brown, bituminous.....		4
Limestone, gray.....		9
Shale, very calcareous.....	3	0
Shale, brown, bituminous.....		4
Shale, sandy (lower member of Green River formation).....	2	0
Water in Evacuation Creek.....		
	694	5

¹ These members are included in the Ute station sample, No. 7, p. 4.

Section of strata containing bituminous shale beds on north side of White River, Utah, 5 miles east of White River stage station, T. 9 S., R. 25 E., Salt Lake base and meridian.

	Ft.	in.
Shale, gray, fissile.		
Shale, bituminous.....		9
Shale, brown, slightly carbonaceous.....		6
Shale, brown, bituminous.....		2
Shale, brown, carbonaceous.....	4	0
Shale, bituminous.....		3
Shale, brown, carbonaceous.....		9
Shale, bituminous.....		8
Shale, brown, fissile, carbonaceous.....	2	11
Shale, bituminous.....	1	0
Shale, brown, carbonaceous.....	1	3
Shale, bituminous (sample of this bed distilled; see samples Nos. 8 and 9, p. 4).....	3	6
Shale, brown, carbonaceous.....	2	4
Shale, bituminous.....		6
Shale, brown, carbonaceous.....	3	2
Shale, bituminous.....		7
Shale, brown, carbonaceous.....		10
Shale, bituminous.....		3
Shale, brown, carbonaceous.....	4	2
Shale, bituminous (estimated to contain 20 gallons of oil to the ton of shale).....	6	10
Shale, brown, carbonaceous.....		11
Shale, bituminous.....		9
Shale, brown, carbonaceous.		
	36	1

Section of strata containing bituminous shale on Hill Creek, Utah, in sec. 12, T. 13 S., R. 19 E., Salt Lake base and meridian.

	Ft.	in.
Shale, gray, thin bedded.		
Shale, bituminous.....		8
Shale, brown, carbonaceous.....	1	7
Shale, brown, thin bedded, calcareous.....	51	0
Shale, bituminous (see sample No. 11, p. 4).....		9
Shale, gray, thin bedded.....	3	0
Shale, brown, bituminous (contains 15 gallons of oil to the ton of shale).....	1	1
Shale, brown, very sandy.....	1	1
Shale, bituminous; weathers in thin laminae.....	5	4
Shale, brown; weathers tan.....	2	8
Shale, brown, carbonaceous, thin bedded.....	3	8
Shale, bituminous (estimated to contain 10 gallons of oil to the ton of shale).....	1	1
Shale, brown, carbonaceous, thin bedded.....	4	4
Shale, drab; weathers gray; fissile.		
	76	3

Section of strata containing bituminous shale along freight road from Myton to Price via Harper, Utah, 4 miles north of Ninemile Creek, approximately in sec. 12, T. 11 S., R. 16 E., Salt Lake base and meridian.

Shale, thin bedded, olive-green.	Ft.	in.
Shale, brown, bituminous.....		6
Shale, olive-green, sandy.....	10	0
Shale, slightly bituminous, weathers in thin layers (sample No. 10, p. 4, was taken from a 6-inch layer near the top of this bed)...	4	10
Shale, brown, carbonaceous.....		6
Shale, bituminous.....	1	2
Shale, gray, thin bedded.....	9	0
Shale, brown, slightly bituminous.....	1	11
Shale, gray, fissile.....	8	4
Shale, bituminous, weathers fissile (estimated to contain 10 gallons of oil to the ton of shale).....	1	2
Shale, gray, sandy.....	9	0
Shale, brown, carbonaceous.....	5	6
Shale, olive-green, thin bedded.....	14	0
Shale, brown, carbonaceous.....		6
Shale, gray, very sandy.....	8	0
Shale, brown, carbonaceous.....		10
Shale, greenish gray, sandy.....	13	0
Sandstone.		
	88	3

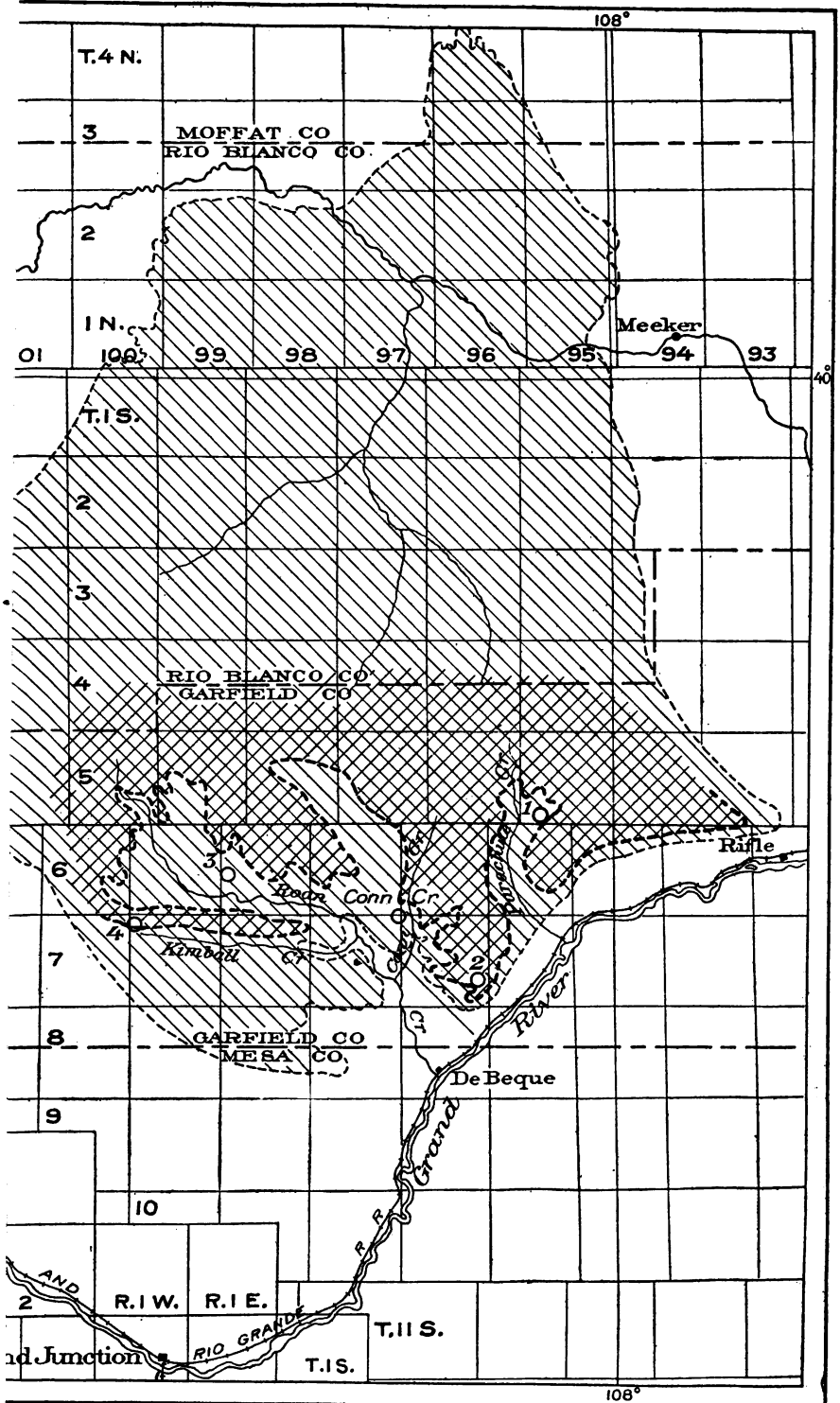
Section of strata containing bituminous shale on west side of Indian Canyon Creek, about 18 miles southwest of Duchesne, Utah, T. 6 S., R. 7 W., Uinta special base and meridian.

Shale, drab, thin bedded.	Ft.	in.
Shale, slightly bituminous.....	2	6
Shale, very sandy.....		9
Shale, brown, carbonaceous, sandy.....		8
Shale, drab, thin bedded.....	71	0
Shale, brown, carbonaceous.....		7
Shale, drab, thin bedded.....	7	0
Shale, brown, carbonaceous.....		6
Shale, drab, fissile.		
	83	0

A sample was taken from an old prospect entry on Conn Creek, Colo., in sec. 1, T. 7 S., R. 98 W. The prospect was opened on what appears to be a lens of bituminous shale, which measures 16 inches in its thickest part. As shown by the field tests described on page 4 and by the laboratory test on page 6, this shale is very rich in hydrocarbons, but it is too thin to be of much commercial value.

STRUCTURE.

The Uinta Basin is a very broad, shallow syncline that lies between the Uinta and Yampa plateaus on the north and the Uncompahgre Plateau, La Salle Mountains, and Beckwith Plateau on the south and extends from the Grand Hogback in Colorado to the Wasatch



NOUS SHALE.

Mountains in Utah. This syncline is divided into an eastern and a western part by a low anticline extending from Dragon, Utah, northward beyond Rangely, Colo.

Minor faults occur at various places. A few in the vicinity of Dragon, Utah, are of the normal type, but the character of the others could not be determined because of the reconnaissance nature of the work. The area seems to have been involved in a broad gentle structural movement, with the local intensive action evident. It is probable that some crustal movements formed the fissures in which the remarkable veins of gilsonite occur, but as yet no conclusive explanation of the origin of the gilsonite has been offered.

In areas occupied by bituminous shale the beds are either horizontal or only slightly inclined. In that part of the Colorado area that was surveyed the rocks dip gently to the north, except in the southeastern part, where they are horizontal. In Utah also the strata dip to the north but at slightly greater angles, though at no place are the dips greater than 14° .

BURNING OF SHALE ALONG THE OUTCROP.

Near Rowley's ranch, on Parachute Creek, 8 miles northwest of Grand Valley, Colo., the cliffs are strewn with slag produced by the burning of the bituminous matter in the shale. The burning appears not to have extended for more than one-fourth mile along the escarpment nor to have penetrated beyond 300 feet in depth, as shown in valleys that have been eroded through the clinker. Burning seems not to have been so intense as in some of the coal beds of this region, but the rocks have reached a temperature high enough to bake the shale to pink, red, or yellow and locally to fuse it to a slag. The burning shows that the shale carries a high percentage of bitumen, else the action could not have taken place.



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, ¹DIRECTOR

BULLETIN 581—B

OIL AND GAS IN THE WESTERN PART OF THE
OLYMPIC PENINSULA, WASHINGTON

BY

CHARLES T. LUPTON

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—B



WASHINGTON
GOVERNMENT PRINTING OFFICE

1914

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IV

OIL AND GAS IN THE WESTERN PART OF THE OLYMPIC PENINSULA, WASHINGTON.

By CHARLES T. LUPTON.

INTRODUCTION.

High-grade paraffin oil is reported to have been discovered in the western part of the Olympic Peninsula, Wash., as early as 1881. Since then attempts to obtain oil or gas in commercial quantities by drilling have been made from time to time in different localities in this region, but without success. Within the past few years interest has been aroused in oil seeps near the mouth of Hoh River and in gas vents in other parts of the field to such an extent that many persons have been attracted to this country to search for oil and gas. As a result of this interest and on account of the fact that efforts had been made to lease tracts of land for this purpose in the Queniult Indian Reservation, an examination of this region was made by the United States Geological Survey at the request of the Office of Indian Affairs. The results of the investigation, which are enumerated below and which are discussed in detail throughout this report, suggest that certain parts of the field are worthy of careful consideration by oil operators. The following summary includes the most important facts regarding the area examined:

High-grade paraffin oil issues from two seeps near the mouth of Hoh River, and at other localities oil-saturated sandy clay ("smell mud" of the Indians) is exposed. Natural gas containing about 95 per cent methane escapes from a conical mound just north of the mouth of Queniult River and also from an inverted cone-shaped water-filled depression on Hoh River a short distance west of Spruce post office. Other minor gas vents are also known in this field and are described in detail in this report. Three wells—one in the reservation about 1 mile north and slightly west from Taholah, another near the mouth of Hoh River, and the third about 1 mile south of Forks—are being drilled for oil and gas. So far as drilling has progressed none of these wells have encountered oil in paying quantities, but all of them have struck small amounts of gas. A

study of the structure and stratigraphy in addition to the examination of oil seeps and gas vents reveals the fact that several anticlines, which may serve as reservoirs for oil and gas, exist in the area examined and that they have apparently a close relationship to the oil seeps and occurrences of "smell mud."

FIELD WORK.

The information set forth in this report was collected during an eight weeks' reconnaissance in 1913. Although the field work in this region was done primarily in order that the Queniult Indian Reservation, which includes about one-third of the area shown on the accompanying map (Pl. II, p. 78), could be classified with regard to coal, oil, gas, and other minerals, yet it was necessary to make a careful study of the area surrounding the reservation, because it contains the oil seeps and the localities from which are obtained many of the data that make possible an interpretation of the stratigraphy and structure in the reservation.

Field examination, which was entirely reconnaissance in character, was made on foot and by canoe, as it was impracticable to use horses to much advantage on account of the few and poorly constructed trails and roads and the presence of an almost impenetrable growth of underbrush. The best and most continuous exposures occur along the coast and the larger streams. The coast and the valleys of Hump-tulips, Moclips, and Hoh rivers were traversed on foot, whereas canoes were used in the reconnaissance of Queniult, Queets, and Clearwater rivers. In attempting to traverse the streams by canoe it is advisable to procure the services of men who are well acquainted with the various streams, as dangerous log jams and "skukemchucks" (bad rapids) are rather numerous. All the streams heading in the Olympic Mountains and flowing into the Pacific are so swift that progress upstream can be made only by poling.

The writer did not visit all the outcrops along the routes traversed in the valleys of Hump-tulips, Moclips, and Hoh rivers, but examined those exposures most easily reached by short side trips from the trails and roads.

The annual rainfall in the Olympic Peninsula is greater than that in any other section of the United States, and for that reason the forests of spruce, fir, cedar, and hemlock, and the underbrush are dense and jungle-like, so that detailed work on the uplands is rendered very slow and tedious and in many places passageways have to be cut through the exceedingly dense undergrowth. Field work away from streams and the coast is unsatisfactory for the additional reason that the older rocks in the uplands are covered almost entirely with a thick mantle of clay, sand, and gravel of Pleistocene age, and this in turn by soil.

The locations of outcrops and places where the dip of the strata was measured are shown approximately with relation to natural landmarks, such as promontories, bends of rivers, and mouths of streams, on Plate II (p. 78). A Gurley compass with clinometer attachment was used to measure the dip of the strata.

ACKNOWLEDGMENTS.

The writer desires to acknowledge the numerous courtesies extended by officers of the Jefferson Oil Co., Big Creek Timber Co., and the Washington Oil Co. The Jefferson Oil Co., which operates near the mouth of Hoh River, and the Washington Oil Co., which operates near Forks, generously furnished the writer with the logs of their wells and other information of value in this report. Residents of the field and many other persons extended courtesies and furnished information which the writer appreciates and for which he can express his thanks only in this general way.

HISTORY OF DISCOVERY AND DEVELOPMENT.

Oil is reported to have been first discovered about 30 years ago on the beach in the vicinity of Copalis Rock, which is about 3 miles north of Copalis and 6 or 7 miles south of Moclips. Persons traversing the beach noticed at this place an offensive odor similar to that of coal oil, and on investigation found that the bluish sandy clay¹ that outcrops here was impregnated with petroleum gas. At certain times of the year the small streams flowing from this locality are reported to have shown "colors" of the oil.

Early in 1901, twenty years after the discovery, the Olympic Oil Co. was organized and began drilling near Copalis Rock. When the drill reached a depth of 160 feet it encountered a strong flow of gas, which burned with a yellowish-white flame 15 feet high. This occurred about the last of April, 1901, and it is reported that in June of the same year oil was struck in small quantities at a depth of 360 feet. This well was drilled to a depth of 850 feet at a cost of about \$10,000, and had to be abandoned on account of a crooked hole. Another well was drilled at Copalis to a depth of 350 feet by the Eldorado Oil Co., in the same year. No oil was obtained, but a flow of excellent artesian water was procured and is still used for domestic supplies at Copalis. It is reported that this well penetrates bluish sandy clay for its entire depth, the proportion of sand increasing with the depth.

It is also reported that in 1901 a drilling outfit was taken to the mouth of Hoh River for the purpose of drilling a well in the vicinity but that after several months of useless effort the plan was abandoned.

¹ Sandy clay with the odor of petroleum is called by the Indians throughout this region "small mud."

In the meantime the west coast of the Olympic Peninsula north of Grays Harbor had been more thoroughly examined and many outcrops of sandy clay partly saturated with petroleum ("smell mud") had been found.

A well was drilled to a depth of about 550 feet at a point approximately in the NW. $\frac{1}{4}$ sec. 1, T. 27 N., R. 15 W., 3 miles southeast of La Push, in 1902, by the La Push Oil Co. It is reported that the upper 150 feet of the rocks penetrated by the drill consists of shale and gray sandstone, whereas the lower 400 feet consists of bluish sandy clay. All rocks penetrated in this well are reported to have a strong odor of petroleum. "Rainbow" colors in small quantities were seen on the water taken from the well at various stages in the drilling, but no accumulation of oil was discovered, the colors being as noticeable on the water obtained near the top of the hole as from that taken from the bottom. Reagan,¹ who described this well briefly in his report, states that "the side pressure was so great that it caved in the pipes, and the work had to be abandoned without any oil having been obtained."

No drilling was done in the field from 1902 to 1912. Prospectors, however, during this interval were on the alert, and evidences of oil were discovered at various places along the coast between Cape Flattery and Point Grenville, a few miles north of Moclips. Arnold,² who examined a part of this field in 1904, in this description of the "supposed Cretaceous" rocks states:

Indications of oil are also very noticeable in a soft gray sandstone, which may belong to this series, outcropping in a canyon about a mile north of Point of the Arches. This oil has a similar odor to that found in the serpentine and conglomerate a mile or so to the north and may be derived from the shales associated with the sandstone. Indications of oil are also said to have been discovered in the sandstones and shales south of the mouth of Quillayute River and at one or two other localities between the Quillayute and Cape Elizabeth.

Reagan,³ who made certain studies in the Olympic Peninsula from 1904 to 1908, and who follows Arnold in his description of the formation in this region, says:

Indications of oil are very noticeable in the soft gray sandstone of this series ("supposed Cretaceous") about a mile south of the Point of the Arches, and also at several locations on the coast south of the Quillayute River. Oil springs also occur on Hoh Head, a mile north of the mouth of Hoh River. Oil is also said to have been found at several places down the coast south of the Hoh.

Near the end of the report Reagan⁴ adds:

Wherever this Miocene formation is exposed there are oil indications, either in the occurrence of the odor of benzine or an allied product of crude oil, or in seepages. The

¹ Reagan, A. B., Some notes on the Olympic Peninsula, Wash.: Kansas Acad. Sci. Trans., vol. 22, p. 234, 1909.

² Arnold, Ralph, Geologic reconnaissance of the coast of the Olympic Peninsula, Wash.: Geol. Soc. America Bull., vol. 17, p. 460, 1906.

³ Op. cit., p. 162.

⁴ Op. cit., p. 234.

latter are most prominently developed along the coast from the mouth of the Hoh River to the mouth of the Quillayute River. On Hoh Head, near the mouth of the former stream, oil forms in pools so that one may dip it up with a cup. This oil is said to be one of the best-grade oils ever found, having a 45 per cent paraffin base.

The presence of oil at Hoh Head, as described above, is reported to have been discovered in the winter of 1906-7 by members of a surveying party. The oil was first seen under the root of a stump near a bear wallow. It was not, however, until December, 1911, that any excavation was made. At that time young men of the neighborhood, in an effort to collect some oil, set off a blast which loosened the adjacent rocks and permitted the oil to flow into a prospect shaft. Previous to this time probably not more than 2 gallons of oil had been collected from this seep, which is now generally known as the Jefferson Oil Co.'s seep, as it is situated near the place where that company is drilling. When the writer visited this locality in August, 1913, a well-cribbed shaft about 18 feet deep, 5 feet long, and $3\frac{1}{2}$ feet wide had been made. A section of rocks exposed in this shaft is given on page 47.

Soon after the discovery of the high-grade oil at Hoh Head several companies were organized for the purpose of drilling for oil and gas on the west slope of the Olympic Peninsula. The first to commence operations was the Washington Oil Co., which located a well on the Anderson farm in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 9, T. 28 N., R. 13 W., about 1 mile south of Forks, and began drilling in October, 1912, with an 82-foot standard rig. In March, 1914, this well had been drilled to a depth of more than 1,600 feet.

The first showings of oil occurred at a depth of 950 feet, but gas in small quantities was present in practically all strata below a depth of 120 feet. At a depth of approximately 1,300 feet three hard oil-bearing strata, each about 3 feet thick, were encountered. The drillers reported the gas pressure at this horizon to be sufficiently strong to lift the 1,300-foot column of water and to force it about 15 feet above the top of the casing. When the writer visited this well in August, 1913, the drill had penetrated to a depth of about 1,200 feet. The odor of gas was distinctly noticeable 100 yards from the well, especially when the tools were being withdrawn. The gas, which burns with a bluish-white flame 3 to 5 feet in height, could be ignited directly after the hoisting of the bailer from the well, which at that time contained about 1,100 feet of water. Although some gas issued continuously from the well, yet larger quantities escaped when the water was agitated by the removal of the tools.

An oil seep, locally known as the Lacy seep, situated on the divide between Mosquito Creek and Hoh River at an elevation of about 425 feet above sea level, was discovered in the NW. $\frac{1}{4}$ sec. 11, T. 26 N., R. 13 W., about 5 miles northeast of the mouth of Hoh River.

The oil at this place was first seen in a bear wallow. The oil mixed with mud probably formed an excellent ointment for keeping disagreeable insects away. In June, 1913, a shaft 16 feet deep, 5 feet long, and 4 feet wide was opened.

Both the Jefferson Oil Co.'s seep and the Lacy seep were discovered by following bear trails to their wallows as above stated. It is quite probable that a number of other seeps may be found by the same means. Owing to the great difficulty in traversing the ridges and streams on account of the dense underbrush, fallen logs, and swamps, a thorough examination of this section has not been made and can not be made without a great deal of labor and expense. Although the Lacy seep is only 5 miles directly east of the Jefferson Oil Co.'s seep, and on the same divide, it is almost impossible to go from one to the other in a direct line. The route traveled is about 6 miles longer than the direct distance.

The Jefferson Oil Co. began drilling with a 72-foot standard rig in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 12, T. 26 N., R. 14 W., September 10, 1913. They reached, according to report, a depth of about 870 feet by February 1, 1914. This well is situated about 1,800 feet south and slightly west from the seep first described and on the same anticline, which extends in a northeast-southwest direction. When the writer last visited this well, in the early part of October, 1913, the drill had penetrated to a depth of 445 feet. Gas was escaping from the well in small volume, as shown by the bubbling of the water in the casing. There was also a slight trace of oil in the material brought to the surface by the bailer from the bottom of the hole.

The difficulties of drilling in this region are very much greater than in a locality where roads are numerous and are kept in good repair. In order to bring the machinery and lumber to Hoh Head, it was necessary to transport them by boat to the fairly good harbor for small boats situated just south of Hoh Head. Here the scow on which the machinery and lumber were loaded was brought near shore and a donkey engine—a necessary piece of machinery in these timbered countries—was taken to the top of the terrace, about 300 feet high, over a skid road one-fourth mile in length. All machinery was brought over the skid road to the site of the well by means of the donkey engine and a large sled.

At the time the writer examined the field a well was being drilled by the Indian Oil Co. about a mile northwest of Taholah, approximately in the NW. $\frac{1}{4}$ sec. 35, T. 22 N., R. 13 W., near the Garfield gas mound hereinafter described. A 64-foot rig and a rotary drill propelled by gasoline power was used. Such an outfit seems fairly well adapted for penetrating the soft sandstones and shales already encountered. Drilling was begun at this place in October, 1913, and, according to report, had reached a depth of a little more than 330 feet in January, 1914.

The well originally was 9½ inches in diameter. In order to set a 10-inch casing and leave sufficient space outside the casing for the free circulation of mud and water, which is necessary when drilling with a rotary outfit, the hole is being enlarged to 14 inches in diameter. It is probable that drilling will be resumed before this report goes to press. This well, which is only 10 miles from the terminus of the railroad at Moclips, is most easily accessible to those interested in the field, and probably will be the first well to prove or disprove the presence of oil in connection with the gas escaping from the Garfield mound, the apex of which is only 125 feet S. 30° W. from the mouth of the well.

Gas is present in small quantities in practically all the wells thus far drilled in the field. In addition it is known to be escaping from several natural vents examined by the writer, and is reported from a number of others not visited. The most prominent of the vents examined is the Garfield gas mound, so named because it is situated on the land of an Indian by that name. This mound is located on a terrace about 250 feet above sea level in the NW. ¼ sec. 35, T. 22 N., R. 13 W., a short distance southwest of the Indian Oil Co.'s well near Taholah. This cone-shaped mound is about 50 feet in height and from 250 to 300 feet in diameter at the base. The gas escapes principally from a small mud-filled crater-like depression, 2 to 3 feet in diameter, situated at the apex. Small quantities of gas escape from other vents near the top of the mound. In September and October, 1913, a barrel had been securely anchored with a gas jet fixed in the top over the principal vent, and the gas which collected in the barrel could be burned. A sample of the gas was collected and has been analyzed by the Bureau of Mines. The analysis and a discussion of the characteristics of the gas are given on page 33. The mound has undoubtedly been built up by the mud, which at all times is carried up by the gas and deposited around the mouth of the crater. The age of the mound is doubtful, but it must be recorded in hundreds of years, because the forest is just as dense on the mound as on the adjacent flat land at its base. A spruce tree 3 feet 6 inches in diameter is growing within 25 feet of the vent and an alder 1 foot 3 inches in diameter within 10 feet of the apex.

Another prominent gas vent, the antithesis of the Garfield mound, locally known as the Devils Mush Pot, is situated in the NE. ¼ sec. 35, T. 27 N., R. 11 W., on the south side of Hoh River, about one-half mile west of Spruce post office. The gas here escapes continuously, and in much larger volume than at the Garfield mound, through water which fills a funnel-shaped depression. The "mush pot" is a little less than 60 feet in diameter and is probably 30 feet deep from the level of the water to the apex of the funnel. Although logs and other débris partly fill the depression, yet a pole 22 feet long pushed

vertically into the water did not touch bottom. The gas from this place is almost odorless, burns with a bluish-white flame, and is believed to be of the same quality as that escaping from the Garfield mound. The water through which the gas escapes has a milky color due to the fine sediment continuously brought up by the gas. This minute but continuous erosion, extending through a long period of time, without doubt has produced the funnel-shaped depression.

Gas escapes in a number of places in sec. 8, T. 23 N., R. 9 W., at the upper end of Queniult Lake, and also near by, just above the mouth of Canoe Creek. Although this gas resembles in odor and character of flame that collected from the Garfield mound at Taholah, yet the fact that it occurs near the mouths of streams which have deposited and buried enormous quantities of vegetation suggests that it may be marsh gas and of recent origin. No analysis of the gas from these localities was made.

A small but interesting occurrence of gas was examined by the writer in the NW. $\frac{1}{4}$ sec. 27, T. 28 N., R. 14 W., on the south side of Bogachiel River, about 7 miles southwest of Forks. On the south side of the stream there is a small landslide of soft bluish-gray sandy clay impregnated with petroleum gas. The gas about 75 feet above river level is so abundant that if a small stick is pushed a foot or more into the soft "smell mud" and then removed it escapes in such volume that it can be ignited and will burn for a few seconds.

A small volume of gas escapes near the bridge over Big Creek just above the mouth of Camp No. 2 Creek, at the extreme south end of the area shown on Plate II (p. 78), in the SE. $\frac{1}{4}$ sec. 32, T. 20 N., R. 10 W. Some of this gas was collected, but it could not be ignited; hence it is believed that it is different from the gas in other parts of the field.

Gas was noted escaping through the water on Queniult River, a mile or two above Taholah, and also on Hoh River, near Hough's place, in the southern part of sec. 22, T. 26 N., R. 13 W., about $1\frac{1}{2}$ miles southeast of Hoh post office. The character of the gas escaping at these places was not ascertained.

In addition to these gas-vents, which the writer examined, some others briefly described below are reported. Gas, according to Billy Snell, of Taholah, escapes around the edge of a spring near the center of sec. 26, T. 27 N., R. 12 W., on the north side of Hoh River, about 8 miles west of Spruce. He states that the water in the spring is milky and that the gas burns very much like that at the Devils Mush Pot, a few miles farther up the river.

The Indians at Taholah report that there are other small gas mounds similar to the Garfield mound at different places in the reservation on both sides of Queniult River. They were not very sure of their locations, as they had seen them only on hunting trips.

It is significant that practically all the seeps and vents already discovered are near trails and small settlements. The writer firmly believes that many other oil seeps and gas vents exist in the area shown on Plate II, and that they will be discovered as more and more of the region becomes accessible by the construction of trails and roads.

CHARACTER OF THE OIL.

The samples of oil collected from the seeps north of Hoh River show that it is high grade and has a paraffin base. In reflected light it has a light to dark green color, whereas in transmitted light the color is dark cherry-red. The odor of the oil as it comes from the seep is very much like that of kerosene. Two samples were collected from the seeps north of Hoh River and analyzed by David T. Day in the Survey laboratory with the following results:

Analysis of crude petroleum from the Jefferson Oil Co.'s seep, in the SE. $\frac{1}{4}$ sec. 12, T. 26 N., R. 14 W.

Physical characteristics.

Color.....	Light green.
Odor.....	Like Pennsylvania oil.
Specific gravity.....	0.8679.
Equivalent to.....	31.5° Baumé.

Distillation.

Begins to boil at.....	103° C.
100° to 125°.....	$\frac{1}{2}$ per cent gasoline.
125° to 150°.....	7 per cent gasoline.
	7 $\frac{1}{2}$ per cent gasoline.
150° to 175°.....	7 per cent kerosene.
175° to 200°.....	9 per cent kerosene.
200° to 225°.....	10 per cent kerosene.
225° to 250°.....	12 per cent kerosene.
250° to 275°.....	16 per cent kerosene.
275° to 300°.....	9 per cent kerosene.
	63 per cent kerosene.

- Average specific gravity of kerosene, 0.8545.

Mr. Day states that the oil contains no asphaltum and that the residuum yields a large percentage of paraffin wax.

Analysis of crude petroleum from Lacy seep, in the NW. $\frac{1}{4}$ sec. 11, T. 26 N., R. 13 W.

Physical characteristics.

Color.....	Dark green.
Odor.....	Like Pennsylvania oil.
Specific gravity.....	0.9365.
Equivalent to.....	19.5° Baumé.

Distillation.

Begins to boil at.....	190° C.
Up to 250°.....	4 per cent kerosene.
250° to 275°.....	10 per cent kerosene.
275° to 300°.....	14 per cent kerosene.
	28 per cent kerosene.

Mr. Day in commenting on this sample says:

The specific gravity of the kerosene oil fraction is rather high on account of the initial boiling point of the oil. The quality of the distillate, however, is like that of Pennsylvania oil. The oil contains no asphaltum but considerable paraffin wax. The residuum from the kerosene distillate is well suited for the manufacture of lubricating oil and paraffin wax.

The above analyses show that the oil taken from the Jefferson Oil Co.'s seep on Hoh Head is much lighter than that taken from the Lacy seep 5 miles farther east. This difference in specific gravity is believed to be due partly to the character of the rocks through which the oil filters into the seeps. The oil enters the Jefferson Oil Co.'s seep through soft sandy clay, which has some of the characteristics of fuller's earth, whereas the rock through which the oil enters the Lacy seep is much coarser and consists principally of sand and gravel. The oil issuing through the less porous rock, like that at the Jefferson Oil Co.'s seep, probably more nearly represents the oil under thick cover than does the oil issuing through coarser material like that at the Lacy seep, where the lighter, more volatile fractions, such as gasoline, have escaped into the atmosphere, leaving the heavier portions behind to flow into the seep. Not only the absence of gasoline but also the greater specific gravity of the sample collected at the Lacy seep seems to support the statement made above in explanation of the difference in the specific gravities of the two samples.

The oil from this region is unlike the oil from the California fields, which has an asphalt base but resembles that from the Katalla district of Alaska, according to the statement of Martin,¹ who, in discussing the oil of the Katalla district, says: "The petroleum is clearly a refining oil of the same general nature as the Pennsylvania petroleum. It resembles the latter in having a high proportion of the more volatile compounds and a paraffin base and in containing almost no sulphur."

CHARACTER OF THE GAS.

Gas from the Garfield gas mound was analyzed by George A. Burrell in the laboratory of the Bureau of Mines, with the following results:

Analysis of natural gas from the Garfield gas mound in the NW. $\frac{1}{4}$ sec. 35, T. 22 N., R. 13 W.

	As received.	Air free.
Carbon dioxide.....	2.67	2.67
Oxygen.....	.28	.00
Methane.....	94.38	95.65
Ethane.....	1.52	1.54
Nitrogen.....	1.15	.14
	100.00	100.00

¹ Martin, G. C., *Geology and mineral resources of the Controller Bay region, Alaska*: U. S. Geol. Survey Bull. 335, p. 124, 1908.

The heating value of this gas at 0° C. and under 760 millimeters pressure is 1,305 British thermal units. Its specific gravity is 0.72 of that of air.

Mr. Day, who also examined this gas, states: "The gas has none of the odor characteristic of marshy emanations and gives evidence of being deep-seated gas, although there is no odor of oil or other indications of its being connected with oil."

As heretofore stated, the gas escaping from the Devils Mush Pot, near Spruce post office, and also that escaping in sec. 8, T. 23 N., R. 9 W., at the upper end of Queniult Lake, are similar, in regard to odor and character of flame, to the gas collected from the Garfield mound, the analysis of which is given above.

GEOGRAPHY.

LOCATION AND ACCESSIBILITY.

The area examined, which is shown on Plate II (p. 78), lies on the west slope of the Olympic Peninsula (see fig. 1) and is bounded by meridians 123° 45' and 124° 40' W. and parallels 47° 8' and 48° N. It is approximately 60 miles long, from north to south, and about 25 miles wide from east to west.

The southern part of the field, extending as far north as the Clearwater River basin, is most easily accessible from the Northern Pacific Railway, which has its western terminus at Moclips, situated on the coast at the mouth of Moclips River and approximately 163 miles by rail from Seattle. Taholah, a small Indian village at the mouth of Queniult River, and other settlements along Queets and Clearwater rivers can be most easily visited by following the beach at low tide to the mouths of these streams. There is a fairly good wagon road from Moclips to Taholah, but northward from this place almost to the northern edge of the area shown on Plate II, in the vicinity of Forks and Quillayute, there are no wagon roads. Persons desiring to enter this country must either travel on foot or horseback along the beach and the very poor trails which lead into the interior. The settlements along the rivers are, however, most easily reached from the mouths of the streams by means of canoes. An automobile stage connects Aberdeen and Hoquiam with Humptulips. Between Humptulips and Queniult Lake there is a poor wagon road, but the State is now constructing a highway, which, it is planned, will be extended northwestward to the vicinity of Clallam Bay and from that locality eastward around the peninsula.

The settlements on Hoh River and also those in the vicinity of Forks and Quillayute are tributary to Seattle by way of Clallam Bay. A daily mail stage connects Mora, a few miles from the coast on Quillayute River, and Forks, in the northern part of T. 28 N., R. 13 W.,

with Clallam Bay, which has daily steamer connections with ports on Puget Sound. Clallam Bay is estimated to be approximately 125 miles by boat from Seattle. It is 31 miles or a day's ride by stage from Clallam Bay to Forks, at the northern extremity of the

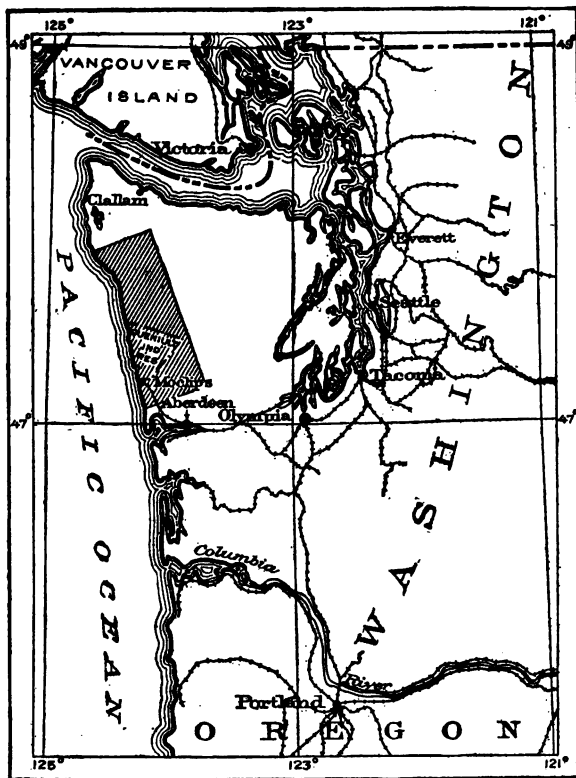


FIGURE 1.—Index map of western Washington, showing location of area examined.

field. The principal trails in the interior of the field are shown on the map' (Pl. II, p. 78). Away from these trails traveling is exceedingly difficult and in many places almost impossible on account of the dense growth of timber and underbrush.

WATER RESOURCES AND VEGETATION.

This field is included in one of the areas of greatest rainfall in the United States. At Tatoosh Island, just off Cape Flattery, 25 or 30 miles northwest of this area, the mean annual rainfall for 22 years is about 88 inches. Near the center of this field, at Clearwater post office, the average annual rainfall for 10 years is a little more than 128

inches. The mean annual precipitation at Aberdeen, which is situated about 15 miles south of the field, for a period covering 11 years, is in excess of 86 inches. From these figures it seems safe to assume that the mean annual rainfall in the area shown on Plate II is at least 100 inches. The natural result of this great precipitation, combined with a mean temperature of about 49° F. and extremes of temperature ranging from 11° to 100° F., is that dense forests of spruce, fir, cedar, and hemlock, with an almost impenetrable growth of underbrush, consisting of salal brush, salmon berry, devil's club, and other bushes, cover the greater part of the field, with the exception of a few comparatively small "burns" and "prairies." The latter name is applied to open spaces in the forests where the larger vegetation has not existed recently and where considerable farming is carried on. Good examples of these are the Humptulips and Forks "prairies," situated at the south and north ends of the field, respectively.

The large annual precipitation above mentioned necessarily makes all the streams perennial. Humptulips, Queniult, Queets, Clearwater, Hoh, Quillayute, Bogachiel, Calawa, and Soleduck rivers and many of the larger creeks are navigable for canoes throughout the greater part of their courses in this field, and many of them can be used to good advantage as logging streams. Hoh River, which has the highest gradient and swiftest current, is rather dangerous for canoeing, especially in its upper course. Logging is extensively carried on along Humptulips River. Moclips River, which is a comparatively small stream, flows through an excellent cedar forest and is used to float shingle bolts to the mill which is situated at Moclips, near the mouth of the stream.

Queniult Lake, situated at the east end of the Queniult Indian Reservation, is about 200 feet above sea level and has an area of approximately 6 square miles. It derives its water from the upper part of Queniult River, Canoe Creek, and several smaller streams, and is drained by the lower part of Queniult River.

TOPOGRAPHY.

The topography of the area shown on Plate II (p. 78) ranges from flat lands at many places near the coast to mountains 20 to 30 miles inland. The greater part of the area is included in an uplifted, much eroded, and somewhat terraced coastal plain of Pleistocene age, in which swift mountain streams have entrenched themselves. The larger rivers have not only cut through the Pleistocene deposits, which are 100 to 300 feet thick, but have also eroded their channels in the underlying, more resistant Miocene and older formations, whereas the smaller rivers and creeks have not yet cut through the Pleistocene cover. In places along the coast this old plain has been

raised above sea level as much as 400 feet, but at other localities the uplift is not so great. The valleys of the larger rivers, the Queets and the Hoh, are marked by at least two prominent terraces. Precipitous cliffs, ranging from 50 to 300 feet in height, are numerous along the coast and at many places along the principal streams. In places the watersheds consist of broad, swampy uplands into which the minor streams have not penetrated, thus suggesting that the topography is still comparatively young. The relief ranges from sea level to 1,500 feet or more at the tops of the high ridges in the vicinity of Queniult Lake on the eastern edge of the area. The terraced lowlands slope with slight breaks from the base of the mountains to the coast, whereas the mountains rise almost precipitously from the floor of the old coastal plain.

In the vicinity of Queniult Lake the topography is typical of that of glaciated areas. In fact, the basin of Queniult Lake itself is believed to be due to a glacier, which emerged from the Olympic Mountains through the U-shaped valley of the upper Queniult River, and which deposited the moraine that now forms the dam at the lower end of the lake. The present topography in the northern and northeastern parts of this field is believed to be partly due to glaciation.

STRATIGRAPHY.

CHARACTER AND AGE OF THE ROCKS.

The surface rocks of the greater part of the area represented on Plate II consist of poorly consolidated clay, sand, and gravel of Pleistocene age. Rocks of the older formations are rarely exposed, except along the coast and the larger rivers. The smaller rivers and creeks in but few places have cut through this Pleistocene veneer except near the coast and the mountains, where it is comparatively thin.

The older rocks in the field, which are unconformably overlain by the Pleistocene material, as stated above, are exposed only along the coast and the larger streams. Arnold,¹ who examined the north coast and the greater part of the west coast of the Olympic Peninsula in 1904, classes the rocks outcropping on the west coast between the northern edge of the area shown on Plate II southward to a point about 1 mile north of Cape Elizabeth (location H), as "supposed Cretaceous." He states that they—

consist almost entirely of a coarse gray sandstone with occasional zones of black shale and rarely a little conglomerate. The thickness of the formation is probably over 5,000 feet, although, owing to its complex structure, this is only a very rough approximation. The series is characterized by calcite veins, which are abundant in nearly all of the exposures. The shales carry some lignite at two or three places, at one locality in particular the coal being used locally for domestic purposes.

¹ Arnold, Ralph, Geological reconnaissance of the coast of the Olympic Peninsula, Wash.: Geol. Soc. America Bull., vol. 17, pp. 459 and 460, 1906.

He then continues with a discussion of evidences of oil in this formation, as quoted on page 26 of this paper.

In this same report Arnold¹ describes three formations—Crescent, Clallam, and Queniult—which lie between the “supposed Cretaceous” below and the unconformable, poorly consolidated Pleistocene beds above. The Crescent formation is assigned to the Eocene series and is described as consisting of “a 1,200-foot series of black basalt and greenish basalt tuffs and tufaceous sands found in the vicinity of Port Crescent” on the north coast.² No outcrops of this formation were recognized in the area shown on Plate II (p. 78).

The Clallam formation, which he assigned to the Oligocene and Miocene series, is described as follows:

Resting unconformably upon the Eocene and older rock of the Olympic Peninsula is a series of conglomerates, sandstones, and shales rich in fossils and extensive in occurrence. The formation is well exposed between Clallam Bay and Pillar Point to the east and for that reason is here named the Clallam formation. * * * A portion of the formation is unquestionably the equivalent of the Astoria sandstones and shales occurring at the mouth of the Columbia River, 130 miles farther south.

The rocks exposed in the hills south of Bogachiel River, according to Arnold, belong to the same formation. He also believes that the thickness of the formation in the vicinity of Cape Flattery is approximately 15,000 feet. Continuing the description of this formation at the type locality, Arnold states:

The conglomerates of the series are usually quite coarse and hard and consist of pebbles and cobbles of quartzite, jasper, black slate, and occasional granitics. They are found mostly at the base and near the top of the series along the straits and in the middle of the series on the Cape Flattery promontory. * * * The sandstones of the Clallam formation are for the most part thin bedded, hard, and resistant to erosion, and are extremely fossiliferous in certain localities, notably east of Clallam Bay. * * * The shale of the Oligocene-Miocene occurs principally in the middle of the formation along the strait (Juan de Fuca). The lower part of the shale is thinly and plainly laminated, but higher up becomes almost massive clay. * * * The shale is gray in fresh exposures, but becomes more or less oxidized upon exposure. * * * Coal occurs in the sandstones east of Clallam Bay, in the upper part of the Oligocene-Miocene series, and in the base of the same series in the vicinity of Freshwater Bay.

No coal of economic value is known to be present in the area represented on Plate II.

The Queniult formation, which Arnold assigns to the Pliocene,³ outcrops in—

a great syncline between Capes Elizabeth and Grenville, through the trough of which Queniult River empties into the sea. The formation in which this syncline is devel-

¹ Arnold, Ralph, op. cit., pp. 460-465.

² In a later report by Arnold and Harold Hannibal (*The marine Tertiary stratigraphy of the north Pacific coast of America: Am. Philos. Soc. Proc.*, vol. 52, No. 212, p. 573, and correlation table opposite p. 604, 1913) the Crescent formation is considered to be the stratigraphic equivalent of the Arago formation.

³ In the report of Arnold and Hannibal, published in 1913 (op. cit., pp. 589, 591, 592, and table opposite p. 604), the Queniult formation is stated to be of Miocene and Pliocene age and to include the stratigraphic equivalents of the Empire and Merced formations.

oped is therefore named the Queniult. The Queniult consists of over 2,200 feet of conglomerates and shale, with minor quantities of sandstone. The conglomerates are developed north of the river, while the shale with some underlying sandstone occurs south of it.

Numerous fossils were collected by Arnold in both the Clallam and Queniult formations.

Unconformably overlying the Tertiary rocks above mentioned are the poorly consolidated beds of clay, sand, and gravel of Pleistocene age, which in places are 300 feet or more in thickness. Beds of very poor peatlike lignite occur in these rocks both along the coast and Queniult River.

Weaver,¹ in a preliminary report on this general region, published a map which shows that in his opinion the rocks outcropping on the west coast are principally "undifferentiated lower Miocene," with a few exposures of "pre-Tertiary metamorphics" and a formation of upper Miocene age which he designates the Montesano formation.

The writer collected but few fossils in the field and so has little information to add to the existing knowledge regarding the paleontology of the region. An attempt is made in the discussion of the various rock outcrops to correlate them with the formations named and described by Arnold, a summary of which is given above.

METHOD OF PRESENTATION OF THE GEOLOGIC DATA.

In the study of the stratigraphy as well as the structure of this field outcrops of rocks along the coast and in the valleys of the principal rivers were carefully examined at places indicated by letters on the map (Pl. II, p. 78). The structure at these places is shown by dip and strike symbols. Wherever anticlines or upfolds are present lines indicating their axes are shown. The anticlinal axes are not extended far from known outcrops.

It seems advisable in a report on this region, where information regarding the character and thickness of the formations is so meager, to describe the outcrops principally by districts rather than by formations and groups. So in the following discussion the writer has described the outcrops of rocks and their structure in regular order along the coast from south to north—from Copalis to a point about a mile north of Hoh Head—and along the streams from their mouths toward their sources. The rocks that outcrop on the coast are described first. Then follows the description of the rocks examined along the rivers and creeks. In describing these outcrops the stream valleys are considered in order from south to north as follows: Humptulips River, including parts of Camp No. 2 and Stevens creeks; Moclips River, Queniult River, Queets River, including parts of Salmon River and Mathney and Sams creeks; Clearwater River as far

¹ Weaver, C. E., A preliminary report on the Tertiary paleontology of western Washington: Washington Geol. Survey Bull. 15, Pl. A, 1912.

east as the west boundary of the Olympic National Forest, Hoh River, and parts of Bogachiel and Calawa rivers at the extreme north.

ROCKS EXPOSED ALONG THE COAST FROM COPALIS TO HOH HEAD.

The rocks exposed along the coast between Copalis and Hoh Head are believed to include the "supposed Cretaceous," the Quenilt formation (now regarded by Arnold as of Miocene and Pliocene age), and beds of clay, sand, and gravel of Pleistocene age, in addition to a small upfaulted block of the metamorphic rocks in the vicinity of Point Grenville. Some of the rocks exposed at a few localities are very similar to those described by Arnold as belonging to the Clallam formation, of Oligocene and Miocene age.

From Copalis north to a point a short distance south of location A, near Copalis Rock, the beds exposed along the coast are almost flat-lying, poorly consolidated rocks of Pleistocene and Recent clay, sand, and gravel. The rock exposed at location A, near Copalis Rock, consists of a bluish sandy clay, which in places gives off an odor of petroleum. Large fragments of dark conglomerate, greenstone, gray limestone, and coarse gritty sandstone, all cut by thin irregular veins of quartz and calcite, are intermixed with the bluish sandy clay. These fragments come apparently from the "supposed Cretaceous," the same kind of rock as that which constitutes Copalis Rock, which lies about 1,200 feet from shore. The exposure here may be due to upfaulting of the "supposed Cretaceous" rocks or it may be due to a rough surface of the older rocks not wholly concealed by the Pleistocene cover. Owing to poor exposures it was not possible to measure the dip and strike. A well at this locality was drilled for oil in 1901 to a depth of 850 feet but without success, as stated on page 25.

Pleistocene clay, sand, and gravel, forming cliffs in places as much as 75 feet high, are fairly well exposed along the coast between Copalis Rock (location A) and a point about 1 mile east and slightly south of the extreme end of Point Grenville (location D). For the most part these beds lie flat, but here and there dips are noticeable. At location B soft yellow and gray sandstone that dips 3° - 4° SE. and strikes N. 55° E. is exposed. About a mile farther north, at location C, the beds consist of chocolate-colored to yellowish, soft argillaceous and conglomeratic sandstone which dips about 4° NE. and strikes N. 65° W. Just north of the mouth of Moclips River the beds lie practically flat.

In the vicinity of Point Grenville (locations D and E) there are metamorphic rocks which are believed to be in an upfaulted block of the old metamorphic rocks that constitute the core of the Olympic Mountains. These strata which show along the coast from location D to location E are very much broken by faults. A number of large castle-like rocks, situated from a few hundred feet to possibly as much

as a mile offshore, probably belong to the same formation. At location D numerous fragments of metamorphic rocks, some of which seem to be in place, lie along the beach. The beds dip 40° N. and strike N. 65° W. Little more need be said than that these old rocks which form Point Grenville consist partly of conglomerate, sandstone, and slate, much faulted and broken and cut by veins of quartz.

In the southwestern part of sec. 18, T. 21 N., R. 12 W., a few hundred feet west of the road leading from Moclips to Taholah, some very much faulted rocks which are believed to be a part of the Queniult formation are exposed. These rocks are situated about halfway between location D and the southern extremity of Point Grenville. At location E there is evidence of a fault trending approximately N. 40° W., separating the older rocks from the Queniult formation to the north. Directly north of this fault there is a prominent slide due to fractures in the strata adjacent to the fault.

Between locations E and F strata of the Queniult formation are well exposed. For a short distance north of location E the beds consist of yellowish-gray conglomeratic sandstone that lies almost horizontal for about 200 yards; the dip then increases gradually to as much as 25° N. and the strike is N. 85° W. A short distance farther north an overlying soft, friable concretionary yellowish-gray sandstone dips only 21° and strikes practically east. A short distance south of the point where the Taholah-Moclips road descends to the beach the massive conglomeratic sandstone beds of the Queniult formation are terminated abruptly by a small fault. For a short distance north of the fault along the coast they seem to be replaced by soft, sandy clay, gravel, and conglomerate which lie nearly flat. A little farther north the dip of these beds increases from 5° to 25° S., thus forming a small syncline a short distance south of the point where the road leaves the beach between locations E and F. The Queniult formation in this locality is stained a yellowish color by limonite, which has seeped from the overlying Pleistocene beds. Between the point where the Moclips-Taholah road descends from the upland to the beach and location F these strata are very much disturbed, being broken by small faults and folds and in places dipping as much as 62° NE. From point Grenville to location F these rocks are capped by Pleistocene clay, sand, and gravel, in places as much as 100 feet thick. Near the base of this material springs are fairly numerous. Between location F and Taholah the surface rocks along the coast consist of Pleistocene and Recent sand, gravel, and clay. From location G, just north of the mouth of Queniult River, to location H, about a mile north of Cape Elizabeth, the Queniult formation is again well exposed. At location G the formation consists of yellowish-gray sandstone and conglomerate

interbedded. Conglomerate seems to be more abundant in this locality than in the same formation south of the river. A short distance north of location G the beds dip 21° SE. and strike N. 35° E. About one-fourth mile northwest of location G the beds dip about 13° SE. and strike N. 60° E. From this point northwestward the beds dip at slight angles to the south and then gradually flatten and continue nearly horizontal to a point a short distance south of location H, where the dip increases to 10° SE. and the strike is N. 20° E., the bed being approximately the same as that on which the dip and strike were measured at location G. Just south of location H the Queniult formation dips 17° SE. and strikes N. 35° E.

As stated on page 28, the Indian Oil Co. is drilling a well at a point about one-half mile north of location G. The rocks penetrated in the greater part of the well are the same as those exposed on the coast between locations G and H, whereas the black shale at the bottom of the section may be represented at the surface by the dark shale that outcrops in the vicinity of location H. The record of the well given below states the character and thickness of the strata penetrated and also indicates at what depths gas and traces of oil were encountered.

Log of the Indian Oil Co.'s well, in the NW. $\frac{1}{4}$ sec. 35, T. 22 N., R. 13 W., near Taholah.

[Compiled from the driller's statement.]

	Thickness.	Depth.
	<i>Ft.</i> <i>in.</i>	<i>Ft.</i> <i>in.</i>
Sand and sandy clay, soft, with soil and poorly consolidated clay, sand, and gravel at top (first gas was encountered at 121 feet and continued to increase to a depth of 295 feet).....	155 0	155 0
Sandstone and argillaceous sandstone, alternating with sandy shale; 60 per cent of this material is hard rock.....	140 0	295 0
Sandstone, brown, very hard.....	13 7	308 7
Sandstone, soft, very porous (much gas and traces of oil).....	13 5	322 0
Sand, very loose.....	3 0	325 0
Sandstone, coarse.....	5 0	330 0
Shale, black (contains gas and strong showings of oil).....	5 0	335 0

At location H and to the north, for about 1,500 feet along the beach, rocks are exposed which are different from those along the beach between locations G and H. These rocks consist of bluish sandy shale and shaly sandstone interbedded and are somewhat faulted and inclined at different angles. At one place the beds dip $32\frac{1}{2}^{\circ}$ NE. and strike N. 60° W., but in most places it was impossible to obtain good measurements of the dip and strike, owing to slumping and the presence of faults. It is believed that these beds of bluish shale are included in an upfaulted block of the "supposed Cretaceous" of Arnold's classification. The exposures along the coast afford no indication of the inland extent or direction of these faults.

The rocks lying north of the blue shale described above, situated near location H, are in many respects similar to those exposed between

locations E and F, south of the mouth of Queniult River. A few hundred feet south of location I, near the point at which the horse trail descends to the beach, beds of sandstone that dip 31° S. and strike N. 75° E. are exposed. Approximately at location I bluish sandy clay interbedded with yellowish argillaceous sandstone is exposed. These beds dip 19° SE. and strike N. 27° E. A little farther north along the coast soft, friable argillaceous, almost massive sandstone, containing much mica and some concretions, outcrops. It dips 26° SE. and strikes N. 15° E. A short distance north of location I there is an abrupt change in structure, the beds dipping 18° E. and striking N. 5° W. The character of the rocks on which the above measurements were taken is practically the same as that of the rocks at location I.

At location J, in the SW. $\frac{1}{4}$ sec. 15, T. 22 N., R. 13 W., beds of soft, friable yellowish-gray sandstone are fairly well exposed. They dip 39° SE. and strike N. 50° E. About three-fourths of a mile farther north, at location K, directly north of the mouth of Camp Creek, the formation consists of soft gray sandstone containing concretionary lenses of hard calcareous sandstone. The surface of these beds is stained yellow in many places with limonite. The strata dip 57° SE. and strike N. 27° E. From location K northward along the coast to location L, in the northeastern part of sec. 4, T. 22 N., R. 13 W., the same formation is fairly well exposed. At one place about 1 mile north of location K the beds dip 47° E. and strike N. 10° E. A measurement was made just south of the point where the trail descends to the beach at location L, which shows that the beds dip 10° E. and strike N. 5° E. The rocks consist of friable argillaceous sandstone containing small gray clay balls and a few pebbles of harder material. A short distance, possibly 600 or 800 feet north of location L, the same formation dips 28° SE. and strikes N. 15° E. The rocks at this place more nearly resemble the rocks exposed on the coast near Copalis Rock, location A, a few miles north of Copalis, than do any of the strata exposed between locations A and L. A few hundred feet north of location M, just south of the "Little Hogback," dark sandy clay having an odor of petroleum is exposed. In traversing the coast the writer made a careful examination for this "smell mud," but at no place between locations A and M is any known to be present. The rocks along the sea cliff in this part of the coast have slumped considerably, and in places the unconsolidated Pleistocene materials are intermixed with rocks slumped from the older formations. At some places the strata are very much disturbed by small folds and faults. Just north of the "Little Hogback," at location M, the strata dip 60° SE. and strike N. 35° E. Between location N and the mouth of Raft River the rocks are fairly well exposed. Just south of the

mouth of this stream there is a bold promontory which at high tide is practically an island and in which the water has worn large cavities and tunnels. On this promontory the strata are much contorted, forming, in a distance of 150 yards, two small synclines with an anticline between them. The general dip of the strata at this place is 50° NW. and the strike N. 65° E. Just north of Raft River a massive grayish-blue sandstone is well exposed in a high cliff. It was impossible on account of the massive character of the rock to determine the dip and strike on this outcrop. On one of the small islands near shore, however, the beds dip 53° NW. and strike N. 25° E. About 600 or 800 feet north of the mouth of Raft River a prominent fault trends approximately N. 80° W. and cuts out on the north the massive grayish-blue sandstone described above. The inclination of the fault plane is almost vertical. North of this fault there is a zone about 50 feet wide in which the rocks are very much crushed, so that the dip of the strata could not be determined. These strata in places give off the odor of petroleum. Between locations O and P, a short distance south of the mouth of Kalaloch Creek, the rocks consist of nearly flat-lying beds of clay, sand, and gravel of Pleistocene age, which are stained yellow here and there by limonitic water. A thin bed of very poor lignite is present in these beds about half a mile north of the mouth of Quail Creek.

At location P, just south of the mouth of Kalaloch Creek and about 100 yards from the water's edge at low tide, a massive grayish-brown sandstone, stained yellow in places, is fairly well exposed. It is so massive that it is impossible to determine its dip and strike. The rocks exposed along the coast for about a mile north of the mouth of Kalaloch Creek consist of Pleistocene clay, sand, and gravel, which in places contain some lignite. The best exposure of this material was noted just south of location Q, in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 4, T. 24 N., R. 13 W. The greatest thickness of the lignite is 5 feet and it is very impure. It contains many roots, stumps, and branches of trees which have been but slightly altered since their deposition. The cliff at this place is about 60 feet high and is made up of flat-lying strata of Pleistocene age. A short distance north of location Q "supposed Cretaceous" strata are well exposed. They consist of alternating thin beds of dark and light sandy shale and shaly sandstone from 2 to 3 inches in thickness, which dip 50° E. and strike approximately north. For a mile or more to the north along the coast the same formation is well exposed, but at location R these beds abruptly give place to the unconsolidated Pleistocene material for about one-third of a mile. At location R the strata dip 38° SE. and strike N. 12° E. The rocks exposed at location R, just south of the place where the Queets-Hoh trail descends to the beach, consist of

coarse yellowish-brown massive sandstone that contains in places a few pebbles and some hard brown spherical and irregularly shaped concretions, the cementing material of which is iron. At location S, near the center of sec. 28, T. 25 N., R. 13 W., the medium-bedded, yellowish gray "supposed Cretaceous" sandstone, much folded and in places possibly cut by slight faults, is again exposed, dipping in general 55° SE. and striking N. 25° E. At location T, about one-half mile north of location S, the sandstone is yellowish brown, coarse grained, and in places conglomeratic. It dips about 77° SE. and strikes N. 15° E. About one-third of a mile north of location T the beds are also very much disturbed. At one place about 100 yards north of location T the rocks consist of alternating beds of sandstone and shale, which dip 47° SE. and strike N. 18° E. At another place near by hard gray sandstone, locally stained yellow, dips 82° SE. and strikes N. 15° E. At this place all the strata are overlain unconformably by the Pleistocene beds, which in addition to clay, sand, and gravel contain 3 to 4 feet of poor lignite. A short distance farther north the "supposed Cretaceous" beds are vertical and strike N. 70° E. These beds extend along the coast to location U, in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 21, T. 25 N., R. 13 W. Northwestward from location U to location V, a short distance north of the mouth of Steamboat Creek, the rocks exposed at the surface consist of clay, sand, and gravel of Pleistocene age. Just north of location V there are exposed thin alternating beds of sandy shale and shaly sandstone of different colors, in appearance resembling somewhat the stripes in a flag. The beds at location V, which are similar to the beds exposed at location Q, dip 60° E. and strike N. 8° E. At various places from location V northward to the mouth of Cedar Creek "supposed Cretaceous" rocks are exposed at low tide. They are quite hard, much jointed, and fractured, so that reliable dip and strike readings are difficult to obtain. At location W, just south of the mouth of Cedar Creek, prominent dark conglomerate in columnar form projects from the sand and gravel along the beach. The pebbles contained in the conglomerate are of different colors, ranging from white through gray and yellow to brown, and the largest are one-third of an inch in diameter. These pebbles resemble in size and appearance the gravel brought up by the bailer from a depth of 450 feet in the Jefferson Oil Co.'s well, a few miles to the northwest. The dip of the strata at location W is approximately 40° NW. and the strike is N. 73° E. This dip and strike measurement was obtained on a prominent mass of rock which extends into the ocean 100 yards north of the mouth of Cedar Creek and which at high tide is an island but at low tide is connected with the mainland. Just north of the mouth of Cedar Creek the soft sandy clay resulting from the weathering of the "supposed Cretaceous" rocks gives off an odor of petroleum and is the characteristic "smell mud" of this general region. Yellowish-gray

sandstone of the same formation as that above described is exposed about one-half mile north of the mouth of Cedar Creek. It dips 33° N. and strikes N. 80° E. For about a mile along the coast northward from this point the surface rocks are of Pleistocene age. They form a cliff 100 to 150 feet in height, from which large slides have occurred in the poorly consolidated sand and gravel. From the north end of this exposure, at location X, to a point about one-fourth of a mile south of the mouth of Hoh River, sandy clay very much disturbed by slumps and slides is exposed. It was impossible to obtain any dip and strike readings on these rocks, but at location Y, just east of the old dance hall at the Hoh Indian village, the strata are well exposed, dipping 29° E. and striking N. 10° W. About one-fourth of a mile south of location Y "smell mud" is plentiful. It is reported that oil seeped from this sandy clay profusely until it was covered by a slide that occurred a few months previous to the time of the writer's visit. Since that time no one has been able to discover any evidence of oil issuing from the sea cliff.

Between the mouth of Hoh River and a point on the beach about 1 mile north of Hoh Head, near the center of sec. 2, T. 26 N., R. 14 W., the "supposed Cretaceous" rocks are well exposed. The most prominent feature is a narrow anticline, the axis of which extends in a northeast-southwest direction through the northern part of sec. 13 and the southern part of sec. 12 of the same township, and presumably through the center of sec. 7, T. 26 N., R. 13 W. At location Z, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 18, T. 26 N., R. 13 W., "smell mud" is very plentiful. At this place the rocks which give off the odor of petroleum consist of alternating "flaglike" beds of yellowish-gray argillaceous sandstone and chocolate-brown soft clay shale. These beds are folded and disturbed, so that a reliable measurement of the dip and strike could not be made. Just northwest of location Z there is a very narrow anticline. The strata near location Z dip about 41° NE. and strike N. 40° W., whereas a little farther north the dip is 54° NE. and the strike N. 50° W. There are so many small folds and faults that no two measurements of the dip and strike agree. Near this locality and about one-third of a mile north of the mouth of Hoh River a dip of 26° N. and strike of N. 80° W. was measured on a bed of greenish-gray sandstone overlain by coarse sandstone and conglomerate, the largest boulders of which are 18 inches in diameter. A short distance south at low tide it was possible to determine that the beds flatten to a dip of 15° N. and the strike changes from N. 80° W. to N. 80° E. on the same stratum.

At location AA, a few hundred feet northwest of location Z, beds of resistant conglomerate and greenish-gray sandstone are well exposed. The sandstone, in the form of small lenses and beds 40 to 60 feet thick, is interbedded with the conglomerate, which is com-

posed of pebbles and boulders ranging in size from sand grains to boulders 3 feet in diameter. The beds are much jointed and folded, and at one point on the south flank of the major anticline on which the Jefferson Oil Co.'s seep is situated they dip about 77° SW. and strike N. 55° W.

The rocks exposed at location BB consist of bluish-gray argillaceous sandstone and interbedded thin sandy shale, which dip 40° SE. and strike N. 35° E. Approximately 75 per cent of the mass is sandstone and the remainder is shale. All these rocks are much jointed and slickensided, showing that they have been subjected to great pressure and movement. Owing to the presence of slides and slumps of "supposed Cretaceous" rocks and also of the overlying Pleistocene material, exposures are poor for about one-third of a mile north of this outcrop and almost an equal distance to the south.

The Jefferson Oil Co. drilled a well to a depth of 868 feet at a point about one-third of a mile north of location BB. The section of strata penetrated by the drill is as follows:

Log of the Jefferson Oil Co.'s well at Hoh Head, in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 12, T. 26 N., R. 14 W.

[Drillers' record.]

	Thickness.	Depth.
	<i>Fect.</i>	<i>Fect.</i>
Mud.....	8	8
Sand.....	5	13
Sand and slate.....	5	18
Shale.....	5	23
Do.....	17	40
Sand.....	5	45
Sand and slate.....	5	50
Shale.....	20	70
Sand.....	5	75
Shale.....	5	80
Sand and shale.....	5	85
Shale.....	35	120
Sand and shale.....	5	125
Shale.....	25	150
Sand.....	3	153
Shale.....	37	190
Sand.....	3	193
Shale.....	7	200
Sand.....	4	204
Slate.....	23	230
Sand.....	5	235
Slate.....	20	255
Sand and slate.....	5	260
Slate.....	15	275
Sand and slate.....	20	295
Slate (contained a little gas).....	16	311
Sand.....	3	314
Slate.....	26	340
Sand (contained gas).....	2	342
Slate.....	38	380
Do.....	40	420
Sand, coarse with shale.....	91	511
Sandstone, hard.....	3	514
Sand, coarse, clayey.....	88	602
Sandstone, hard.....	10	612
Sand, coarse, clayey.....	35	647
Sandstone, rather coarse (big gas showing).....	13	660
Sand, coarse; some shale.....	115	775
Sand, rather coarse (big gas showing and trace of oil).....	5	780
Sand, rather coarse, clayey.....	85	865
Sand, coarse (very strong flow of gas).....	3	868

* The log below this point is given in much larger units than above.

The section of strata exposed in the shaft at the Jefferson Oil Co.'s seep a few hundred feet north of the well is as follows:

Section of strata in the Jefferson Oil Co.'s shaft in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 12, T. 26 N., R. 14 W.

	Ft.	in.
Soil, dark.....	1	6
Clay, yellowish, sandy.....	9	0
Shale, bluish, sandy (oil saturated).....	7	6
	18	0

The oil seeps from the lower bluish sandy shale and is not present in appreciable quantities in the overlying yellowish clay.

The rocks at location CC, just south of Hoh Head, lie on the north flank of the prominent anticline referred to above. They consist of brownish-gray sandstone interbedded with a small proportion of dark carbonaceous shale. In places the strata are broken by small faults which cut the rocks obliquely to the bedding planes. Lenses of conglomerate, consisting of pebbles and boulders of bluish-gray sandstone, sandy clay, limestone, and quartzite with much lime and iron in the cement are present in the sandstones. Minute veinlets and stringers of calcite or quartz cut all the strata. A little coal (as much as one-half inch thick in places) also occurs in these beds. The strata on the beach dip about 80° NW. and strike N. 28° E., whereas on the hillside, about 100 feet higher, the beds consist of alternating layers of yellowish-brown and gray sandstone and sandy shale which dip 41° NW. and strike N. 15° E.

On the north side of Hoh Head, a few feet east of the trail and possibly a hundred yards from the ocean, a small landslide has exposed bluish sandy shale which gives off the odor of petroleum. It was not possible to measure the dip and strike of these beds. The rocks exposed on the beach just east of location DD consist of bluish-gray sandstone and sandy shale, which weather into bluish sandy mud and in places give off the odor of petroleum. At location DD, on the north side of Hoh Head, several hundred feet of yellowish-brown, somewhat argillaceous sandstone is exposed, dipping approximately 45° SW. and striking N. 65° W. At location EE, which is almost 1 mile north of Hoh Head, gray carbonaceous and argillaceous sandstone containing thin lenses of coaly material one-half inch in maximum thickness is exposed. The general dip of the strata here is approximately 60° E. and the strike is N. 10° W. Some small faults cut the rocks in this locality.

Location EE is the northernmost point along the coast visited by the writer. The rocks exposed farther along the coast for a mile or more apparently belong to the same formation as do those in the vicinity of Hoh Head.

To summarize, the oldest rocks exposed along the coast between locations A and EE are at Point Grenville. Here the old metamorphic series has been upfaulted and is represented not only by the rocks exposed between locations D and E, but also by those very resistant rocks which form the numerous islands in this locality a mile or more from the coast.

The "supposed Cretaceous" rocks are believed not to outcrop south of location H, about 3 miles northwest of Taholah, except possibly at location A, near Copalis Rock. From present knowledge it seems very probable that practically all the strata, with the exception of the Pleistocene clay, sand, and gravel discussed below, that outcrop along the coast between locations H and EE belong to the "supposed Cretaceous" formation. The only other outcrop of rocks of probably the same age are those exposed in a very small area just east of Copalis Rock at location A.

The Queniult formation outcrops in the vicinity of the mouth of Queniult River, between locations E and H. As stated above, some of the rocks exposed in the vicinity of locations J and K very much resemble the Queniult formation at its type locality.

The Pleistocene beds are exposed almost continuously from Copalis northwestward to location D near Point Grenville, and are again exposed continuously for a number of miles in the vicinity of the mouth of Queets River from location O to location Q, with the exception of a small isolated outcrop of "supposed Cretaceous" rocks just south of the mouth of Kalaloch Creek. Farther north along the coast they are also exposed between locations R and S, in the southern part of sec. 28, T. 25 N., R. 13 W., for about one-half mile, and again for a mile or more directly southeast of the mouth of Steamboat Creek, between locations U and V. From a point about one-half mile north of location W, near the mouth of Cedar Creek, the Pleistocene beds are well exposed northward as far as location X. In addition to the exposures along the coast the Pleistocene caps practically all of the exposures of the Queniult formation and the "supposed Cretaceous" rocks.

ROCKS EXPOSED ALONG HUMPTULIPS RIVER, INCLUDING PARTS OF CAMP NO. 2 AND STEVENS CREEKS.

The rocks exposed along that part of the lower course of Humptulips River shown on Plate II (p. 78) and extending as far northeast as the bridge over the river about a mile above Humptulips post office are believed to consist entirely of poorly consolidated clay, sand, and gravel of Pleistocene age. The writer did not make a thorough examination of the lower course of this river, but at all points where the valley was examined these beds are exposed. A very careful examination of the strata was made along Camp No. 2

Creek for about a mile and a half above its mouth, which is about $2\frac{1}{2}$ miles above the junction of Big Creek with Humptulips River, at the extreme southern edge of the area represented on Plate II. The result of the examination along this creek definitely proves that the rocks are of the same age as those exposed along that part of the lower course of Humptulips River shown Plate II, namely, of Pleistocene age. These rocks on Camp No. 2 Creek consist of yellowish-brown conglomerate, with lenses of soft gray sandy clay alternating, immediately beneath soft bedded sandstone, with yellowish-gray sandy clay. Some of the gray sandy clay includes large numbers of fragments of stems of vegetation similar to grass. At one place a very distinct leaf was found in rather hard, yellowish sandy shale. The conglomerate consists of pebbles, probably derived from the metamorphic rocks and also probably from some of the "supposed Cretaceous" sandstones. This conglomerate is much cross-bedded and in places shows evidence of having been deposited by streams. At one locality a piece of lignite about 6 inches thick was found, but at no place along the stream between locations A and B is any lignite exposed in the walls of the valley. The beds lie practically flat, but at one place, about a mile southeast of location A, they dip 6° N. and strike approximately N. 70° W.

At location C, on Stevens Creek, in the NE. $\frac{1}{4}$ sec. 7, T. 20 N., R. 10 W., an extensive outcrop of the Pleistocene beds occurs. These strata are about 75 feet thick and consist principally of poorly consolidated gravel and sand.

About $1\frac{1}{2}$ miles east of Humptulips, on the south side of Humptulips River and about one-third of a mile above the wagon bridge, at location D, there are beds of dark bluish-gray shale which contain thin lenses of iron-stained sandy material and numerous iron nodules. The nodules range from one-half to 1 inch in thickness and some of them are 2 feet in length. The outcrop at this place occurs in the edge of the stream and is entirely covered at high water. It is quite probable that these beds, which dip 69° NE. and strike N. 65° W., are of the same age as those along the coast which have been classed as "supposed Cretaceous."

In examining the outcrops along Humptulips River the writer did not follow the stream channel except in places but traversed mainly the wagon road from which he departed here and there to note the character of the rocks in the valley. At location E, at the bridge in the southern part of sec. 9, T. 20 N., R. 10 W., yellowish-brown fine-grained argillaceous sandstone, somewhat massive in character, is exposed. Owing to the absence of definite bedding planes the dip and strike could not be determined. Just below the forks of Humptulips River, at location F, beds of Pleistocene age are well exposed along the north side of the river for several hundred yards. These beds lie practically flat and consist principally of a poorly consoli-

dated conglomerate with some clay and a little lignite, as shown by the following section:

Pleistocene beds exposed at location F, just below the forks of Humptulips River.

	Feet.
Conglomerate, poorly consolidated.....	40±
Clay, bluish, sandy, soft.....	10±
Lignite, very impure (little more than peat).....	1±
Clay, bluish soft, sandy.....	4±
	55±

The strata are fairly well exposed at a small falls at location G, in the south half of sec. 6, T. 20 N., R. 9 W., just north of the wagon road and a short distance south of Humptulips River. The rocks here consist of a coarse brownish sandstone which in places contains grains and small pebbles of greenish material one-tenth of an inch in diameter. The rocks exposed below the falls are probably 60 to 80 feet thick and are predominantly sandy but less resistant than the rocks directly overlying them. The strata dip 53° SE. and strike N. 65° E. At location H, just north of the wagon bridge over the east fork of Humptulips River, approximately in the SW. $\frac{1}{4}$ sec. 5, T. 20 N., R. 9 W., a great thickness of bluish sandy shale with intercalated beds of shaly sandstone of the same color is exposed. Numerous slides and slumps have occurred here, but the loosened material has been carried away and the bedrock exposed by the frequent "splashings" and "sluicings" at the logging camps farther up the river. The beds dip about 55° SE. and strike N. 26° E. These rocks resemble very much the bluish sandy shale exposed on the beach near Copalis Rock (location A). Rocks having the same characteristics are exposed along the south side of the river in the southwestern part of sec. 5, T. 20 N., R. 9 W. At location I, in the NE. $\frac{1}{4}$ sec. 5 of the same township, about 1 $\frac{1}{2}$ miles upstream from the wagon bridge, yellowish-gray sandstone and sandy shale that dip about 72° NE. and strike approximately N. 40° W. are exposed for a short distance. The easternmost outcrop of sedimentary rocks along the east fork of Humptulips River is at location J, in the NW. $\frac{1}{4}$ sec. 35, T. 21 N., R. 9 W. These rocks, which are well exposed for a short distance along the north side of the wagon road, consist of gray sandy shale, dipping about 66° SW. and striking N. 35° W. This exposure is less than 100 feet west of what is believed to be the contact between the sedimentary and the igneous rocks. Northeastward from location J to East Fork dam (location K) the rocks exposed along the river and wagon road are igneous and are presumably older than those exposed farther west.

The oldest rocks examined along Humptulips River lie between locations J and K, in the southeastern part of T. 21 N., R. 9 W., and are believed to be of igneous origin. Along the river, between

locations D and J, all the rocks examined are considered to be the equivalent of or possibly younger than the "supposed Cretaceous" rocks exposed along the coast in the vicinity of the mouth of Hoh River. The rocks exposed along the lower course of Hump Tulips River and its tributaries and also near the forks of the river consist of Pleistocene clay, sand, and gravel, and, in addition, these same materials cap all the older, more resistant rocks along the river valley. No indications of oil or gas in the form of oil seeps, gas vents, or "smell mud" are known to exist in this valley.

ROCKS EXPOSED ALONG MOCLIPS RIVER.

The rocks exposed along the lower course of Moclips River westward from location A are composed of clay, sand, and gravel of Pleistocene age. At location A, in the NE. $\frac{1}{4}$ sec. 7, T. 20 N., R. 12 W., the following section of rocks, which are believed to belong to the Queniult formation, are well exposed:

Rocks of the Queniult (?) formation exposed along Moclips River at location A.

	Ft.	in.
Sandstone, yellow, friable.....	20	0
Sandstone, very argillaceous; contains thin beds of conglomerate, the pebbles of which range from the size of sand grains to as much as 1 inch in diameter.....	20	0
Conglomerate, yellowish, lower part chocolate-brown to yellow, pebbles and bowlders range in size from sand grains to as much as 10 inches in diameter and consist principally of metamorphic rocks and "supposed Cretaceous" sandstone...	25	0
Lignite, very impure, peatlike (dip 39° SW., strike N. 15° W.)...	1	8
Clay, bluish gray and yellowish, sandy; sand increases in the lower part.....	35	0
Shale, containing thin lenses of lignite.....	1	0
Clay, sandy, carbonaceous, lower part bluish.....	12	0
Conglomerate, containing bluish pebbles, the largest 6 inches in diameter, belonging principally to the metamorphic series...	2	6
Sandstone, yellow, soft, argillaceous.....	3	0
Conglomerate, yellowish; pebbles range in size from sand grains to 3 inches in diameter; about 60 per cent from the metamorphic rocks and the remainder from "supposed Cretaceous" rocks.....	18	0
Poorly exposed (probably consists of conglomerate and sandstone).....	100±	
Sandstone and sandy clay, yellowish.....	15	0
Clay, bluish, containing thin beds of lignite, one at the base about 2 feet thick, the other just above the middle (dip 43° SW. and strike N. 20° W.).....	50	0
Sandstone, yellow and brown, containing a little conglomerate near the middle (dip 45° SW. and strike N. 25° W. near the middle of these rocks).....	120	0
Sandstone, bluish, argillaceous.....	2	0
Sandstone, yellowish and brown, contains little conglomerate..	50	0

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At location B, about 1 mile upstream from location A, the same formation outcrops on the north side of the river. Here the rocks consist of brownish-gray sandstone from which issue many seeps of limonitic water. At this locality the beds dip 10° NE. and strike N. 20° – 30° W., being much more nearly flat-lying than farther downstream. At location C, approximately in the SW. $\frac{1}{4}$ sec. 3, T. 20 N., R. 12 W., sandstone of the Queniult (?) formation is again exposed. The strata dip 15° NE. and strike N. 35° W. The writer traversed Moclips River as far northeast as M. R. Smith's shingle-bolt camp, situated about a mile farther upstream than location B. All the rocks exposed between location C and the above-mentioned camp are of Pleistocene age. The foreman of this camp, who has traversed the entire length of Moclips River and the adjacent country, reports that all the rocks exposed northeast of the camp are practically the same as the beds exposed near the camp, which are of Pleistocene age.

ROCKS EXPOSED ALONG QUENIULT RIVER AND LAKE.

At location A, on the south side and about $1\frac{1}{2}$ miles from the mouth of Queniult River, 400 to 500 feet of soft yellowish sandstone and conglomerate are exposed. The pebbles in the conglomerate consist of hard material stained brown and the largest are 6 inches in diameter. These beds, which dip 23° E. and strike N. 8° E., are believed to be a part of the Queniult formation, which is well exposed along the coast both north and south of the mouth of Queniult River. The same formation is exposed on the north side of the river at location B, about one-half mile east of location A. At this place a little fine-grained conglomerate, capped with slightly consolidated Pleistocene rocks, outcrops a short distance above water level. The strata dip 17° SE. and strike N. 15° E. Southeast of location B several feet of Pleistocene sand and clay is exposed at location C, on the east side of a small creek emptying into Queniult River from the north. At location D, on the south side of the river, in the SE. $\frac{1}{4}$ sec. 6, T. 21 N., R. 12 W., very soft, poorly consolidated sand and conglomerate, similar to those beds described at location A, are well exposed for a short distance. At this place there is a fault and an abrupt flexure of the strata. The fault trends N. 30° W. and is nearly vertical. About 20 feet east of the fault the strata dip 70° NE. and strike approximately N. 60° W., but 50 feet farther east the beds flatten to a dip of about 20° . Southwest of the fault, along the south side of the river, there is a very prominent slide 300 or 400 feet in width, composed of soft blue mud, but no indications of petroleum gas were noted. The exposure of soft bluish sandy mud is bounded on the northwest by a conspicuous outcrop of fairly well consolidated sandstone and conglomerate approximately 125 feet thick. It is probable that a fault separates these beds from the slide, although no definite evidence was obtained regarding it. All the beds at location D

are unconformably overlain by beds of Pleistocene sand, clay, and gravel.

For several miles up the river no Tertiary or older rocks are exposed, but at various places described below the beds of Pleistocene age outcrop and in places contain not only the characteristic clay, sand, and gravel but also thin beds of very impure lignite. This material can hardly be considered lignite, but might more properly be classed as peat. However, the term "lignite" has been already used in this report and hereafter wherever it occurs it will be understood as applied to this very poor peatlike material.

At location E, on the north side of the river opposite Billy Snell's place, a cut bank exposes several feet of bluish sandy clay overlain by a little lignite and unaltered wood, which in turn is overlain by about 25 feet of yellowish-gray conglomerate. The pebbles of this conglomerate consist principally of smooth subangular fragments of metamorphic rocks. In places the boulders reach a maximum size of 18 inches, but for the most part they are less than 6 inches in diameter. At location F, about $1\frac{1}{4}$ miles upstream from location E, beds of Pleistocene age are exposed on the south side of the river for a short distance, and again at location G in the NE. $\frac{1}{4}$ sec. 3, T. 21 N., R. 12 W.

Probably the most prominent exposure of the Pleistocene along the whole course of Queniult River is found at location H, northeast of John Chowchow's place. The bluff on the north side of the river at this place is about 300 feet high, and consists of poorly consolidated yellowish sandstone and grayish conglomerate with a little bluish-gray sandy clay. A detailed measurement of these strata was not made, but from the fairly large pieces of lignite found in the talus near the water's edge it is believed that a lignite bed 1 to 2 feet thick is present in the upper part of the bluff. The beds lie practically flat. The ridge into which Queniult River now impinges to form this prominent bluff trends approximately N. 10° E., but it is not present near the stream on the south side of the valley.

At location I, about 1 mile northeast of location H, on the south side of the river and also southwest of the mouth of a small creek, a bed of resistant dark-gray sandstone overlain by sandy shale is exposed a short distance above the water. This exposure is of small extent and is believed to be the easternmost outcrop of the Queniult(?) formation on Queniult River, but it may be part of the "supposed Cretaceous" formation, in which case it is necessary to assume the presence of a fault or a fold lying to the west. The strata here dip approximately 43° NE. and strike N. 70° W. Between location I and Burnt Hill (location R, described below), a distance of about 15 miles by the river, no rocks older than Pleistocene are exposed along the river banks. These exposures are described hereafter, together

with certain indications of the presence of older rocks near the surface.

At location J, on the south side of the river, about one-third mile west of Tommy Ford's place, about 15 feet of bluish sandy clay, overlain by approximately 20 feet of poorly consolidated conglomerate, is exposed for a short distance. At location K there is a large rapids locally known as Bookrock Rapids, in which numerous large boulders and angular rocks suggest the existence of a ridge or ledge of metamorphic rocks near the surface at this place, unless they have been carried here by the glaciers from Olympic Mountains. A very large erratic at location O, on Queniult River, described below, suggests that these large fragments of rock were brought by ice.

Just upstream from Bookrock Rapids, on the south side of the river, dark-bluish sandy clay about 15 feet thick, overlain by poorly consolidated sand and gravel about 40 feet thick, both of Pleistocene age, is exposed for a short distance. Another very striking exposure of Pleistocene rocks occurs at location L, on the north side of the river, approximately in the NW. $\frac{1}{4}$ sec. 21, T. 22 N., R. 11 W. The greater part of this consists of almost flat-lying beds of bluish sandy clay, sandstone, and conglomerate, as shown by the following section:

Pleistocene beds exposed at location L, on Queniult River.

	Ft.	in.
Clay, sandstone, and conglomerate; capped with soil, poorly exposed.....	20±	
Sand and gravel, poorly consolidated.....	12±	
Lignite, very impure.....		8
Clay, drab, sandy.....	4	0
Lignite, brown, very impure (about 200 feet west the lignite bed is replaced by other rocks).....	3	0
Conglomerate and sand, interbedded with some blue sandy clay; pebbles of conglomerate range in size from sand grains to 6 inches in diameter, and consist of sandstone and fragments of resistant metamorphic rocks.....	50±	
Clay, bluish, sandy, to river level.....	10±	
	99	8

The section above described gives an idea of the thickness of the beds overlying the entire area west of the Olympic Mountains. The bluff in which these strata are exposed is 600 or 700 feet long. At location M, on the south side of the river, about one-half mile west of the mouth of Cook Creek and about 2 miles upstream from location L, there is a bluff 40 to 60 feet high in which bluish clay mixed with sand, gravel, and boulders, the largest of which are 1 foot in diameter, is exposed in the lower 30 feet of the outcrop. Just above this bluish clay about 10 feet of grayish conglomerate is exposed.

The lower course of Cook Creek was examined as far east as location N, a distance of more than a mile. The rocks outcropping along this

portion of the stream are either of Pleistocene or Recent age and consist of poorly consolidated clay, sand, and conglomerate. The banks of the creek are not more than 15 feet high and are covered to the water's edge with a very dense growth of timber and underbrush.

At location O, on the south side of Queniult River and about three-fourths of a mile from the mouth of Cook Creek, there is a large rock approximately 25 feet long, 15 feet wide, and 15 feet high. This rock is very hard and resistant and is similar to that exposed at Burnt Hill, about 6 miles upstream, hereinafter described. It was impossible to determine whether or not this rock is in place, but as no other rocks of similar composition are exposed near by it seems probable that it is an erratic. Its presence here, together with the large boulders described in the vicinity of Bookrock Rapids, 5 or 6 miles below, suggest strongly that glaciers from the Olympic Mountains extended to this locality and brought these immense fragments of rock at least from the vicinity of Burnt Hill if not from the main range east of Queniult Lake.

A short distance upstream from location O, and on the north side of the river, a cut bank exposes about 50 feet of poorly consolidated cross-bedded conglomerate of Pleistocene age. At location P, about one-half mile southwest of the mouth of Boulder Creek, approximately in the western part of sec. 14, T. 22 N., R. 11 W., blue clay of Pleistocene age is also exposed. As large quantities of this clay occur at many places along the streams several miles inland it is suggested that it may be valuable for the making of bricks. It has not been tested, but is believed to be worthy of examination by those interested in such materials. Owing to its location it is not of value at the present time, but in the future, when this region may be rather densely settled, it probably will be of considerable importance.

The Pleistocene beds are well exposed at location Q, on the north side of Queniult River, a short distance northeast of the mouth of Boulder Creek. At this place the lower part of the Pleistocene exposure consists of very fine bluish clay and the upper part of a poorly consolidated conglomerate. There is a marked local unconformity separating the two. The upper 4 inches of clay underlying the conglomerate is stained yellowish gray with iron, which is the principal cementing material of the overlying conglomerate.

No extensive exposures were noted between location Q and location R on the north side of Queniult River, approximately in secs. 1 and 12, T. 22 N., R. 11 W. Location R is locally known as Burnt Hill on account of the vegetation having been burned several years ago. The rock, probably greenstone, exposed in Burnt Hill is dark greenish gray and belongs to those rocks of the Olympic Peninsula that have been designated the old metamorphic series. In places the fractures and joints have a purplish color, but where the rock is

much weathered the color is lighter and has somewhat of a greenish tinge. Two sets of joints cut the rock, one trending N. 55° E. and dipping about 77° NW., and the other trending N. 85° E. and dipping about 80° N. The smooth rounded surface of Burnt Hill suggests that it has been glaciated.

At location S, on the north side of the river, in the S. $\frac{1}{2}$ sec. 5, T. 22 N., R. 10 W., Pleistocene conglomerate approximately 100 feet thick is exposed. At location T, in the S. $\frac{1}{2}$ sec. 35, T. 23 N., R. 10 W., about $3\frac{1}{2}$ miles upstream from location S and about one-half mile east of Shortys Rapids, large amounts of bluish sandy clay are exposed on both sides of the river. The clay is very distinctly bedded and quite soft and slippery when wet. At location U, locally known as the Blue Banks, about $1\frac{1}{2}$ miles upstream from location T, 40 to 60 feet of bluish sandy clay containing thin lenses and beds of gravel overlain by yellowish-gray poorly consolidated conglomerate 30 to 40 feet thick is exposed. The conglomerate is well stratified and dips slightly to the west. Farther up the river, at location V, which lies between location U and the west end of Queniult Lake, the beds of Pleistocene sand and gravel dip to the west at angles as high as 30°. As stated under the heading "Topography" (p. 36) it is believed that without question the Pleistocene deposits in the vicinity of Queniult Lake are of glacial origin and that the lake itself is due to the presence of a prominent terminal moraine crossing the valley in a northwest-southeast direction through the southeastern part of T. 23 N., R. 10 W. The glacial deposits are known to surround the western part of Queniult Lake and are believed to extend for several miles both to the northwest and southwest from the lake. At the northeast end of the lake apparently glaciated metamorphic rocks are exposed and they also show at location W, about one-fourth of a mile west of Higley's hotel. The outcrop at this place is known locally as Onion Rock from its very smooth surface, which is probably the result of glaciation. Two other exposures of similar rock were seen on the same side of the lake and about 1 mile west of Higley's hotel. The remainder of the rocks surrounding Queniult Lake, as far as the writer is aware, belong to the poorly consolidated beds of clay, sand, and gravel of Pleistocene age.

The gas which issues from the water near the upper end of the lake and also near the bridge over Canoe Creek at Higley's hotel escapes through beds of Pleistocene and Recent age.

To summarize, metamorphic rocks are exposed along Queniult River and Queniult Lake at two localities—one at Burnt Hill, in secs. 1 and 12, T. 22 N., R. 11 W., and the other on the north side of Queniult Lake in the vicinity of Higley's hotel. One of the most conspicuous of these outcrops on the lake is known as Onion Rock.

The rocks exposed at locations A, B, D, and I are believed to be outcrops of the Queniult formation, although it is possible that the exposure at location I is composed of "supposed Cretaceous" rocks.

All other exposures along Queniult River and Queniult Lake are believed to be of Pleistocene and Recent age.

ROCKS EXPOSED ALONG QUEETS RIVER FROM ITS MOUTH TO THE MOUTH OF SAMS CREEK AND ALONG THE LOWER COURSES OF SALMON RIVER AND MATHENY AND SAMS CREEKS.

QUEETS RIVER.

The rocks exposed at the mouth of Queets River for about a mile from the ocean consist of beds of clay, sand, and gravel of Pleistocene age. At location A, on the south side of the river, near the center of sec. 35, T. 24 N., R. 13 W., dark bluish-gray sandstone, stained yellow in places with limonite, is exposed for a short distance. The strata dip 70° N. and strike $N. 15^{\circ}$ E. About one-half mile upstream and on the north side of the river, in the vicinity of location B, rocks of the same formation ("supposed Cretaceous") are exposed. They consist of about 200 feet of gray coarse-grained thin to medium bedded sandstone, overlain by approximately 400 feet of dark-bluish sandy shale. The shale is characterized by weathering into small cubes, the joints of which have a conchoidal fracture. The underlying sandstone dips about 38° SE. and strikes $N. 32^{\circ}$ E. Possibly a thousand feet farther upstream the shale dips 48° SE. and strikes $N. 25^{\circ}$ E. Both the sandstone and shale in this exposure are broken by faults and are somewhat contorted by small folds. The upper part (stratigraphically) of the shale is more sandy than the lower part and contains "flaglike" beds, which consist of alternating beds of shaly sandstone and darker sandy shale, each bed of which is generally from 2 to 3 inches thick. A few hundred feet farther upstream the "flaglike" beds overlain by bluish sandy shale dip about 24° SE. and strike $N. 50^{\circ}$ E. At location C, approximately in the SW. $\frac{1}{4}$ sec. 36, T. 24 N., R. 13 W., and on the west side of Queets River, yellowish-gray slightly argillaceous "supposed Cretaceous" sandstone, which dips 29° SE. and strikes $N. 20^{\circ}$ E., is well exposed for a few hundred feet. The shaly "flaglike" beds of this formation are exposed at location D, just above Moses Bend. The strata are so much folded and broken by small faults that dip and strike readings have little value and hence none were made. At location E, on the south side of the river about half a mile farther upstream, a very argillaceous sandstone, which dips 43° NE. and strikes $N. 66^{\circ}$ W., is exposed. About half a mile farther upstream, at location F, in the NW. $\frac{1}{4}$ sec. 31, T. 24 N., R. 12 W., just west of the mouth of Elk Creek, a very massive, much jointed, and fractured dark-gray sandstone outcrops for a short distance along the river bank. The beds dip 58° NE. and strike $N. 30^{\circ}$ W. The "supposed Cretaceous"

rocks are well exposed for several hundred yards along the south bank of the river at location G, near Frank Harlow's place, at the mouth of Clearwater River. The westernmost exposure in this locality consists of the "flaglike" beds of sandstone and shale, which dip about 32° SW. and strike N. 45° E. A few hundred feet farther northeast, in front of the house, dark-bluish iron-stained sandy shale is exposed for about 125 feet. The shale rests with apparent conformity on the "flaglike" beds just described; it dips about 51° NE. and strikes N. 16° W. The apparent discordance in the strike of the rocks at these two places so near each other is due probably to a minor fold. At location H, on the north side of the river, about one-half mile northeast of Frank Harlow's, there is about 40 feet of dark-gray fine-grained argillaceous sandstone that dips 36° NW. and strikes N. 30° E. At location I, in the NE. $\frac{1}{4}$ sec. 28, T. 24 N., R. 12 W., 75 to 100 feet of almost flat-lying beds of Pleistocene conglomerate and sandy clay is exposed.

In the vicinity of the mouth of Salmon River there are broad bottom lands to the south and west of both Salmon and Queets rivers. On the north side of Queets River in this locality and within possibly one-fourth to one-third of a mile of the stream there are terraces 50 to 75 feet above the level of the river flood plain. These terraces consist of practically the same material as that exposed at location I except that it has been worked over by the present stream since Pleistocene time.

At location J, on the north side of Queets River, in the NW. $\frac{1}{4}$ sec. 26, T. 24 N., R. 12 W., 600 to 800 feet of thin-bedded gray "supposed Cretaceous" sandstone is exposed at low water. The bed dips 42° E. and strikes north at the west end of the exposure, whereas it dips 48° SE. and strikes N. 25° E. at the east end. At location K, on Hartzel Creek near its mouth, in the SE. $\frac{1}{4}$ sec. 26, T. 24 N., R. 12 W., a very hard yellowish-brown sandstone, which dips 31° E. and strikes north, is exposed a short distance southeast of the cabin on the Bill Donaldson homestead. On the same side of the river, and about 300 yards upstream from the Donaldson house, hard gray fine-grained sandstone, which dips 47° SE. and strikes from N. 25° E. to N. 65° E., is exposed for a few hundred feet. The strata are also fairly well exposed for about one-half mile at location L, on the south side of the river, in the vicinity of the mouth of Mud Creek. The rocks at the western end of this outcrop, which is about one-third of a mile east of the Steeple place, consist of hard massive quartzitic sandstone overlain by medium-bedded, very dark gray, somewhat argillaceous sandstone. At one place near the west end of the exposures the quartzitic sandstone shows in the river bed at a low stage of water in the form of a half dome. The sandstone is about 20 feet thick and is overlain by more than 300 feet of dark gray argillaceous

sandstone. These strata are affected by small faults and folds. At one place near this dome the beds dip 15° SE. and strike approximately N. 30° E. A few feet west of the point where the last-mentioned dip was measured, and on the east side of a very distinct fault, the beds dip about 10° S. and strike approximately east. A little farther upstream soft argillaceous thin-bedded sandstone overlies the hard sandstone mentioned above, dipping about 51° E. and striking north. About 500 feet farther east "flaglike" beds of the same formation are exposed. They dip approximately 80° NE. and strike N. 40° W. About 800 to 1,000 feet of the "flaglike" beds are exposed in the eastern part of the rather extensive exposures in the vicinity of the mouth of Mud Creek. Near the east end of this outcrop grayish-blue to brown shaly sandstone, which dips 70° SW. and strikes N. 15° W., is exposed. The exposed rocks are much broken by joints cut by veins of quartz and possibly by some calcite, so that reliable dip and strike measurements could not be made. It is believed, however, that this sandstone, 400 feet or more thick, is very similar to the beds exposed at location B, a mile or two above the mouth of the river.

At location M, which is on the south side of the river, about three-fourths of a mile east of the old Evergreen post office and in the northern part of sec. 21, T. 24 N., R. 11 W., blue sandy clay with yellowish and bluish gravel of Pleistocene age outcrops for a short distance. These beds have been disturbed by slumping, so that they now dip about 27° SE. and strike N. 50° E. At a few places along the river beds of Pleistocene clay, sand, and gravel have been disturbed by slumping, so that they now lie in positions much different from those in which they were originally deposited. An example of the disturbance created by one of these slides is well illustrated by a landslide that began about 10 years ago at location N, on the south side of Queets River, just west of the mouth of Matheny Creek and about one-half mile east of location M. At the time this slide began to move the bed of the river seemed to rise and form a dam, so that for a few days the water was ponded and flowed over the broad bottom lands south of the Streater place. A flood that occurred a little later cut a channel through this obstruction in the river bed, so that the principal channel was left in almost the same position as it had been formerly. This phenomenon was believed by some of the settlers to be caused by the expansion of a large quantity of gas underlying the river. Others, however, believed it to be simply a landslide, in which the pressure from the side of the river caused the river bed to buckle, thus forming the dam. The latter explanation is undoubtedly correct, as indications of an immense landslide extending for at least one-fourth of a mile south from the river are very noticeable. It is believed by the writer that additional deformation of the

Pleistocene beds will occur from time to time at this place. The buckling, as one would naturally expect, has left the beds of poorly consolidated clay and sand inclined at various angles, hence wherever marked dips are found it may be assumed that they are due to slumping.

All the rocks exposed along Queets River, from location M, about 1 mile west of the mouth of Matheny Creek, to a point 2 miles up Sams Creek, consist entirely of clay, sand, and slightly consolidated conglomerate of Pleistocene age. Generally the beds are horizontal, but in places they are very much inclined through slumping, as explained above. It is reported that these beds are exposed some distance up Queets River above the mouth of Sams Creek, but as the writer did not traverse that part of the river a confirmation of the report was not made.

Horizontal bluish sandy clay, overlain by conglomerate and soil, is exposed on the east side of Queets River, about one-half mile north of the mouth of Matheny Creek. At location O, in the SW. $\frac{1}{4}$ sec. 10, T. 24 N., R. 11 W., on the north side of the river, the same formation as that outcropping at the mouth of Matheny Creek is exposed for a short distance. The bluish sandy clay, which everywhere weathers into a soft sticky mud, contains at this locality irregular sandy concretions, some of which are in the shape of disks and others are very much elongated, but all of them are flat. At location P, also on the north side of the river, and about a mile farther northeast, the same beds are exposed. They dip 39° W. and strike practically north. The finest clay from this place, after being thoroughly mixed with a certain proportion of milk, has been used by some of the settlers as paint, which is reported to be very durable.

At location Q, on the north side of the river, approximately in the SW. $\frac{1}{4}$ sec. 1, T. 24 N., R. 11 W., and just above the Aker place, flat-lying bluish sandy clay of the Pleistocene formation is exposed for a short distance. At location R, about one-half mile farther upstream, similar bluish sandy clay is exposed, dipping about 36° NW. and striking N. 60° E. The older rocks are not known to be exposed between location R and the Billy Howard place, in the NW. $\frac{1}{4}$ sec. 1, T. 24 N., R. $10\frac{1}{2}$ W., but it is possible that they are present in high tree-covered ridges situated from one-third to three-fourths of a mile back from the river. As these ridges were not visited and no information was obtained regarding them it is impossible to determine the point.

SAMS CREEK.

At location A, at the mouth of Sams Creek, and for a short distance up Queets River on the south side, flat-lying beds of bluish sandy clay were observed. Gas is reported just above the mouth of Sams

Creek, but no evidence of its escape was seen by the writer when the locality was visited in September, 1913. All the rocks outcropping along Sams Creek between location A and location C, in the SE. $\frac{1}{4}$ sec. 34, T. 25 N., R. 10 W., consist of beds of clay, sand, and gravel of Pleistocene age and soil, gravel, and hill wash derived principally from the erosion of these beds.

At location B, approximately in the N. $\frac{1}{4}$ sec. 5, T. 24 N., R. 10 W., the bluish sandy clay, so common along Queets River above Matheny Creek, is exposed for a short distance. This material contains flat sandy concretions similar to those noted at location P, on Queets River. The beds dip about 40° NW. and strike N. 80° E. At location C, which is about a mile downstream from the west end of Sams Creek canyon, hard resistant grayish-brown quartzitic sandstone is exposed for about one-fourth of a mile along the south side of the creek. It was not possible to obtain an accurate measurement of the dip and strike at this place. At location D, on the north side of the creek and a little farther east than location C, Pleistocene bluish sandy clay that dips about 40° NW. and strikes N. 70° E. is exposed for a short distance. At location E, on the south side of the creek and about one-half mile east of location D, quartzitic sandstone similar to that exposed at location C on this creek outcrops for a distance of 600 feet. These beds, which include some interbedded shaly sandstone, dip about 85° NE. and strike N. 50° W. Approximately 500 feet farther upstream the beds flatten so that they dip only 65° NE. and strike the same as at location E. At location F, on the south side of the creek, in the northeastern part of sec. 4, T. 24 N., R. 10 W., about one-half mile southeast of the mouth of the canyon, beds of sandstone and sandy shale, which are slickensided in places and somewhat broken by small faults, are exposed. It is believed that the shale constitutes less than 5 per cent of the rocks exposed. The general dip seems to be 76° E. and the general strike north. At location G beds of sandstone and shale that dip 72° E. and strike N. 55° W. are exposed. At location H, which is about a mile from Queets River and the easternmost point reached on Sams Creek, a bed of shale that dips 69° SE. and strikes N. 50° E. is exposed for a short distance.

Along Sams Creek pebbles of the metamorphic rocks and also the softer and lighter-colored "supposed Cretaceous" sandstones are numerous.

MATHENY CREEK.

The strata exposed along Matheny Creek from its mouth to location A, a distance of about 3 miles, consist entirely of bluish sandy clay and yellowish-brown sandy gravel. The gravel seems to lie unconformably on the clay, which contains the sandy disks and irregular flat concretions noted at location P, a few miles up Queets River

above the mouth of this creek. The Matheny Creek canyon begins at location A and extends for 2 miles or more to the east. The rocks exposed at the mouth of the canyon are principally sandstone with a little sandy shale interbedded, but it is believed that the shale constitutes not more than 2 per cent of the entire thickness of rock exposed. At a point about one-third of a mile up the canyon the beds dip approximately 47° E. and strike N. 3° E. The rocks in general at this place are very much jointed and broken by small faults. About one-half mile above the mouth of Matheny Creek canyon the rocks are the same as those at location A, between which point and the lower end of the canyon fully 800 feet of strata are exposed. At another point in this part of the canyon, a few hundred feet farther upstream from the point at which the dip and strike readings given above were taken, the strata dip 59° E. and strike approximately north.

SALMON RIVER.

The rocks exposed along Salmon River from its mouth to location A, a distance of about 2 miles, consist of sand, clay, and gravel of Recent age, and possibly here and there an outcrop of the underlying Pleistocene beds, but above location A, as far as the writer examined the section, the rocks exposed belong to the "supposed Cretaceous" formation. At location A, on the south side of the river, the rocks consist of grayish-brown soft sandstone and sandy shale. These strata dip 27° SE. and strike N. 33° E. About 75 feet farther upstream on the same side of the river the rocks dip 48° W. and strike N. 5° - 10° E. On account of the discordance in dip and strike it is believed that a fault lies between the two points at which these dip and strike readings were measured. About 150 feet upstream from location A the rocks dip 41° NW. and strike N. 65° E. At location B, about 450 feet upstream from location A, the beds dip 65° NE. and strike N. 55° W. At location C, approximately three-fourths of a mile up the canyon, the same rocks dip 30° SE. and strike N. 25° E. The beds are very much contorted between locations B and C, dipping at many angles and striking in practically all directions. This condition is due not only to small faults but also to numerous small folds. At location D, about a mile up the canyon and near the reservation line, the beds dip 25° E. and strike practically north. At location E, about $1\frac{1}{2}$ miles up the canyon, the strata dip 20° NE. and strike N. 15° W. Location E was the southeasternmost point reached in the examination of the lower course of Salmon River. It is reported that the river flows through two main canyons. The westernmost canyon is said to extend probably not more than a mile east of location E, and the second canyon is reported to lie east of the trail which crosses the river near the Salmon ranger station in sec. 5, T. 23 N., R. 11 W.

SUMMARY.

To judge from the general eastward dip of the older strata along the Queets and Salmon rivers and Sams and Matheny creeks, it seems logical to assume without conclusive paleontologic evidence that the older rocks of the section lie farthest to the west and the younger formations to the east. The rocks exposed farther east along these streams are harder and more resistant than those that outcrop near the coast, but this condition is probably due to the greater metamorphism of these supposedly younger strata lying near the mountains in the eastern part of the section traversed.

The rocks exposed along Queets River from its mouth to the vicinity of location H, a mile or more above the mouth of Clearwater River, are undoubtedly the same beds as those that outcrop along the coast, which in this report have been classed as "supposed Cretaceous." The hard resistant sandstones outcropping on Queets River and along the lower course of Salmon River may belong to the "supposed Cretaceous" formation, but they are undoubtedly younger and lie stratigraphically above the rocks exposed near the mouth of Clearwater and Queets rivers. The beds outcropping in the canyons of Matheny and Sams creeks are probably still younger than the rocks farther west.

The beds of bluish sandy clay and gray to yellowish, poorly consolidated gravel outcropping at different places along Queets and Salmon rivers and Matheny and Sams creeks are, with but little question, of Pleistocene age. The terrace gravel, soil, hill wash, and talus at different places along these streams are entirely of Recent age.

ROCKS EXPOSED ALONG CLEARWATER RIVER WEST OF THE OLYMPIC NATIONAL FOREST.

The strata exposed along Clearwater River west of the Olympic National Forest probably all belong to the "supposed Cretaceous" formation and are better and more continuously exposed than the rocks of any other part of the area examined. (See Pl. II, p. 78.) Although these beds are well exposed, yet the unusual number of folds and small faults makes the interpretation of the structure very difficult. The Pleistocene beds of clay, sand, and conglomerate are exposed at only a few places. In fact Clearwater River runs from the western boundary of the Olympic National Forest to a point about one-fourth of a mile north of Clearwater post office, through a comparatively narrow canyon of the older rocks, whose walls attain a maximum height of 200 feet.

At location A, about one-half mile above the mouth of Clearwater River, on the east side of the stream, there is an exposure of yellowish-brown sandstone and yellowish gravel very poorly consolidated.

These beds lie practically flat and unquestionably can be correlated with the beds of Pleistocene age in other parts of the field. Soft, yellowish-brown sandstone is exposed at location B in the northern part of sec. 30, T. 24 N., R. 12 W., on the west side of the river. The beds here are medium bedded, dip 37° NE., and strike N 30° W. At location C, about one-fourth of a mile farther north, the "flaglike" beds, consisting of thin-bedded sandstone alternating with sandy shale, outcrop on the west side of the river. They dip 73° NW. and strike N. 40° E. The total thickness of the beds exposed here is approximately 800 feet. At the north end of this exposure the strata dip 71° NW. and strike N. 35° – 40° E. The "flaglike" beds of alternating sandstone and sandy shale are exposed at location D, just below the mouth of Hurst Creek, and also for 300 or 400 feet up that stream, where the strata dip 74° E. and strike N. 5° – 10° E. At location E, on the west side of Clearwater River, about one-half mile upstream from the mouth of Hurst Creek, beds of hard dark-gray resistant sandstone about 500 feet thick are exposed. The upper part (stratigraphically) of this exposure is not distinctly bedded, so that dip and strike readings are not reliable. The lower portion of the beds dips 68° W. and strikes N. 5° – 10° E. At location F, on the east side of the river, about 100 feet of "supposed Cretaceous" sandstone dips 49° NW. and strikes N. 55° E. At location G, at the west end of the big bend in the river in the SE. $\frac{1}{4}$ sec. 12, T. 24 N., R. 13 W., the "flaglike" beds, which dip 60° E. and strike N. 5° W., are also exposed. The strata exposed at location H, on the east side of Clearwater River, about three-fourths of a mile east of location G, consist of about 250 feet of the "flaglike" beds, which are overlain unconformably by fairly well consolidated Pleistocene conglomerate at least 100 feet thick. The "flaglike" beds are inclined 30° NE. and strike N. 45° W. The striking differences noted here in angle of dip and in direction of strike are due to abrupt flexures and in places possibly to small faults. At one locality a short distance upstream from location H the beds dip 29° NW. and strike 18° E. The same beds 150 feet farther upstream dip 39° SE. and strike N. 30° E. and at location I, 200 feet farther upstream, the dip is 36° SE. and the strike is N. 65° E. The "flaglike" beds at this place consist of about 60 per cent of sandstone and 40 per cent of shale in beds 2 or 3 inches in greatest thickness. About 300 feet farther upstream from location I the same beds stand vertical and strike N. 55° E.

At location J, on the east side of Clearwater River and about one-third of a mile north of location I, beds of sandy shale dip about 66° NE. and strike N. 25° W. At location K, at the west end of a prominent bend, approximately in the SE. $\frac{1}{4}$ sec. 1, T. 24 N., R. 13 W., the sandstone and shale beds of the same formation as that described above, as far as can be ascertained, dip 55° NE. and strike N. 60° W.

The strata are much disturbed by folds and small faults, as the following dip and strike readings show. At a point 25 feet downstream from location K the beds dip 60° SW. and strike N. 20° W. The fault line separating the points where these two last-mentioned dip and strike readings were taken is very distinct. About 1,000 feet farther downstream the "flaglike" "supposed Cretaceous" beds stand vertical and strike N. 20° W. A few hundred feet farther downstream and on the opposite side of the river beds of massive, much broken sandy shale are exposed, but it was not possible to measure dip and strike readings on these beds. At location L, about 1 mile upstream from location K, the "flaglike" beds dip 87° S. and strike N. 85° W. A short distance downstream from this place the same beds dip 58° SE. and strike N. 30° E. At location M, on the south side of the river, in the northeastern part of sec. 6, T. 24 N., R. 12 W., and 600 or 800 feet northeast of location L, the "flaglike" beds dip 67° SE. and strike N. 70° E. At location N, on the east side of the river and about one-half mile farther north, beds of gray sandstone, which alternate with thin beds of shale, are exposed for a short distance. The dip is 67° E. and the strike N. 10° W.

Exposures are fairly good on the east side of the river from location N southward for one-fourth to one-half mile. Several hundred feet of strata are well exposed in the vicinity of location O, in the northern part of sec. 32, T. 25 N., R. 12 W. At the western end of this exposure the beds, which dip 56° NW. and strike N. 30° E., consist of dark-bluish sandy shale and several hundred feet of "flaglike" beds of alternating sandstone and shale. Many of the joints of these strata are filled with iron-stained calcite. A short distance east of location O beds of gray sandstone, overlain by a few hundred feet of dark-bluish sandy shale, dip 65° W. and strike north. The beds upstream from location O have a brownish tinge, whereas those downstream are bluish black. From the mouth of Elkhorn Creek, which joins Clearwater River in the NE. $\frac{1}{4}$ sec. 32, to location O the river flows through a narrow canyon in the walls of which the "flaglike" beds, together with some dark shale, are well exposed. On the south side of the river in this canyon the beds in places stand almost vertical. At location P, just above the mouth of Elkhorn Creek, strata of similar character that dip 42° NE. and strike N. 20° W. are well exposed for a short distance. A little farther upstream, at location Q, approximately in the SE. $\frac{1}{4}$ sec. 29, T. 25 N., R. 12 W., sandstone beds dip 51° SE. and strike N. 20° E. At location R, on the west side of Clearwater River, about one-half mile northeast of location O, beds of sandy shale that dip 40° SE. and strike N. 25° E. are exposed for 300 or 400 yards. A few hundred feet southwest of location R the strata dip 45° NE. and strike N. 30° W. This dip and strike reading is not so reliable as the readings taken at locations Q

and R. At the mouth of Shale Creek (location S) about 6 feet of sandstone containing calcite in the joints, overlain by bluish-black shale containing hard calcareous nodules, is exposed. The beds at this place dip 63° SE. and strike N. 55° E. About 500 or 600 feet north of the mouth of Shale Creek gray hard fine-grained shaly sandstone is exposed on the east side of Clearwater River. The strata both overlying and underlying this sandstone are poorly exposed, but seemingly consist of dark-bluish sandy shale interbedded with shaly sandstone. They dip 53° NE. and strike N. 45° W.

An unusually long and steep rapid, known locally as the "Skukem-chuck," is situated a few hundred feet upstream from the mouth of Shale Creek. At location T, on the west side of the river, one-third of a mile upstream from location S, about 300 feet of yellowish-gray sandstone and bluish-yellow sandy shale are exposed. In both directions from location T, for at least one-fourth of a mile, dark-bluish sandy shale is exposed in the river banks. These beds are cut by joints and fracture planes which in many places are filled with calcite. The rocks are so much broken by small faults that within a distance of 200 feet beds may be found flat-lying, almost vertical, and dipping 45° , all striking in different directions. At location U, on the east side of Clearwater River and just below the mouth of Miller Creek, there is an outcrop of dark-brown to black clay shale, in which the surfaces of joints and fractures show slickensides. At the mouth of Miller Creek on the north side of the river there is a fairly good outcrop of yellowish-gray sandstone. These beds are so deformed that reliable readings of dip and strike could not be made. At location V, on the south side of the river and about one-half mile farther upstream, the "flaglike" beds consist of soft, dark thin-bedded sandy shale and sandstone, which dip 72° SE. and strike N. 60° E. At the upper end of the outcrop near the bend of the river the beds seem to be overturned. The dip is 89° NW. and the strike N. 65° E. Approximately 300 feet of shale and shaly sandstone outcrop at this easternmost exposure.

On the west side of Clearwater River, beginning a short distance north of Giberson's house, situated in the NE. $\frac{1}{4}$ sec. 27, T. 25 N., R. 12 W., sandstone and sandy shale are exposed almost continuously upstream to the mouth of Christmas Creek. At location W, which is on the west side of the river and about 100 yards below the mouth of Christmas Creek, beds of bluish sandy clay, which dip 33° N. and strike N. 80° W., are exposed. Many small faults and folds were observed here. At location X, about one-half mile south, slightly east of location W, beds of dark sandy shale are exposed on the south side of the river. These beds dip 59° E. and strike N. 10° E. About 100 feet upstream from location X the rocks are cut

by a small fault and about 300 feet farther up the river the same beds dip 48° E. and strike N. 10° – 15° E. Between the fault and the point where the last dip and strike readings were measured, the strata are much contorted and strike more nearly east. At location Y, on the south side of Clearwater River, approximately in the NE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 26, T. 25 N., R. 12 W., beds of sandstone and sandy shale that dip 15° – 20° E. and strike N. 10° – 15° E. are fairly well exposed for a short distance. Some of these beds are "flaglike" in appearance and are similar to those mentioned as occurring at other places along this river. About 500 feet farther up the river "flaglike" beds that dip 24° SE. and strike N. 25° E. are well exposed and are overlain unconformably by poorly consolidated conglomerate of Pleistocene age. At location Z, situated near a bend in Clearwater River, about $1\frac{1}{4}$ miles directly west of the Olympic National Forest boundary, beds of bluish sandy clay and slightly consolidated conglomerate of Pleistocene age are exposed, but the bedding is so indistinct that dip and strike readings could not be obtained. At location AA, on the south side of Clearwater River, in the NE. $\frac{1}{4}$ sec. 26, T. 25 N., R. 12 W., beds of dark-bluish sandy shale, alternating with yellowish-gray medium to thin bedded sandstone, are exposed. The dip at this place is 67° S. and the strike is approximately east. At location BB, in the northern part of sec. 25, T. 25 N., R. 12 W., similar beds of sandstone and sandy shale, containing probably a little more shale than the beds at location AA, dip 85° SE. and strike N. 40° E. At location CC, on the north side of the river a short distance west of the forest reserve line, the same beds, dipping 63° NW. and striking N. 45° E., are also exposed. The "flaglike" beds are exposed fairly well at location DD, on the north side of the river, presumably just west of the boundary of the Olympic National Forest. Dip readings on these beds range from 40° NW. to vertical and the strike is N. 65° E. At location EE, at the bend of the river a short distance above the mouth of Deception Creek, which is the easternmost point visited by the writer during the traverse of this river, beds of sandstone with a little intercalated shale are exposed on the south and east sides of the river. The beds stand almost vertical and strike N. 65° E.

Practically all the rocks exposed along Clearwater River, with the exception of those outcropping at locations A and Z, are believed to belong to the "supposed Cretaceous" formation.

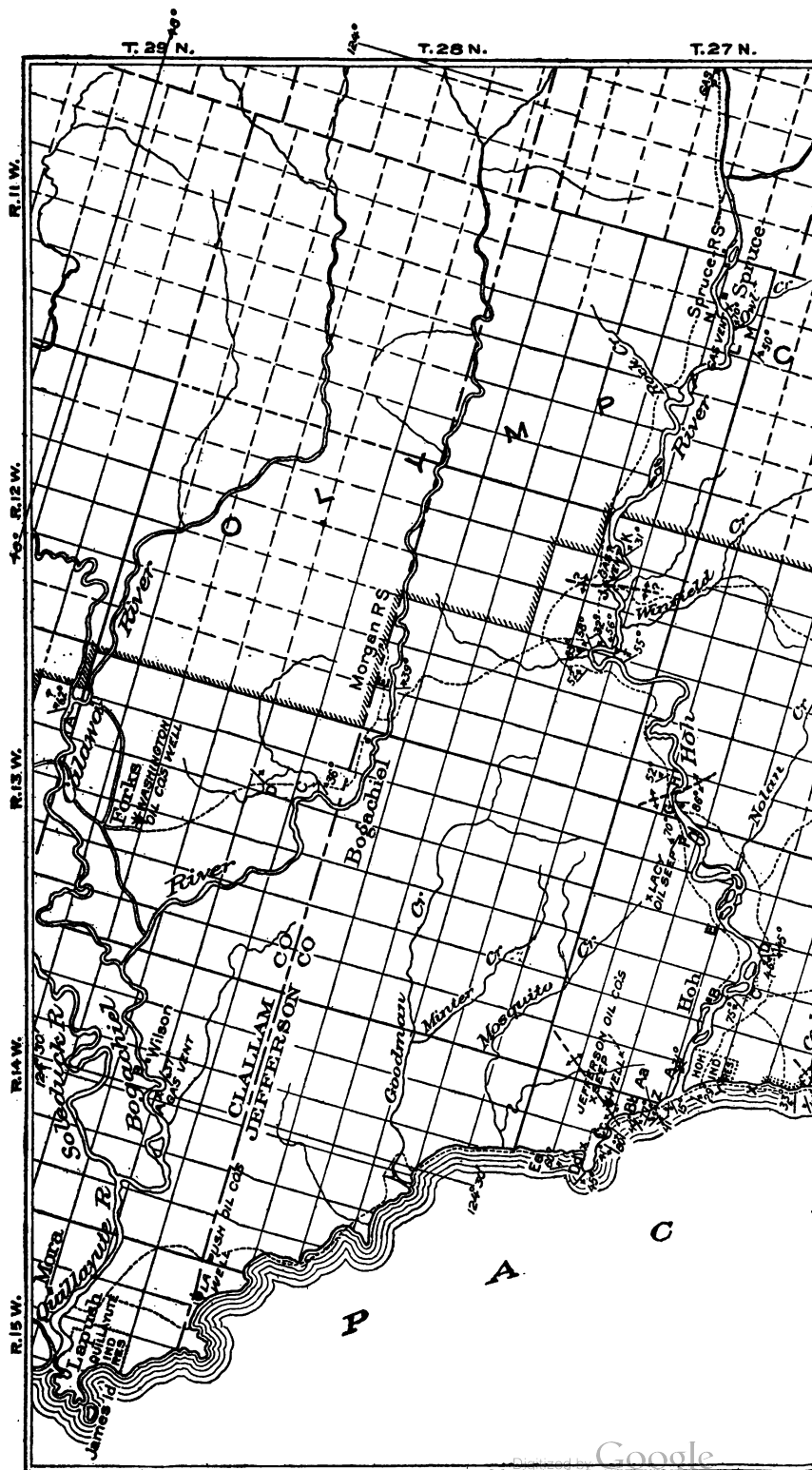
The beds of bluish sandy clay and poorly consolidated sand and conglomerate exposed at locations A and Z and overlying the "supposed Cretaceous" at locations H and Y are of Pleistocene age. The rocks on the uplands are concealed by a thick mantle of soil, hill wash, and talus.

ROCKS EXPOSED ALONG HOH RIVER.

Before the description of the rocks noted along Hoh River is given it seems proper to state that the writer did not visit all the exposures along this stream but only the more prominent ones that could be easily examined when traveling along the principal trail on the north side of the river valley. The stratigraphy and structure along this stream can best be studied from a canoe, but it was impossible, on account of the short time spent in this portion of the field, to make a careful study of the beds exposed in the river banks.

At location A, on the north side of Hoh River, about one-half mile from the ocean, beds of gray sandstone and sandy shale about 75 feet thick are exposed. These beds are much broken by joints and fractures and on account of the presence of many small faults dip at different angles and strike in different directions. They dip approximately 31° SW. and strike N. 55° W. At location B, on the south side of the river, in the SE. $\frac{1}{4}$ sec. 21, T. 26 N., R. 13 W., there is an exposure 100 to 200 feet in length of yellowish-gray thin-bedded, somewhat micaceous sandstone, which dips 75° NW. and strikes about N. 25° E. At location C, on the south side of the river, about one-third of a mile southeast of location B, almost flat-lying beds of bluish sandy clay of Pleistocene age are exposed. At location D, just east of W. D. Hough's house on the south side of the river, a grayish-blue sandstone, which weathers yellow and which is soft when wet, dips 45° SW. and strikes N. 15° W. Another reading taken near by shows that the same bed dips 46° SW. and strikes N. 33° W. About 200 yards downstream from this locality, near an old log jam, bubbles continually rise to the surface of the water. It is possible that these bubbles are formed by escaping natural gas, but more probably they are due to air that has been carried into the water or to marsh gas. Some of the gas was collected, but an attempt to ignite it was unsuccessful. At location E, on the north side of the trail, about 2 miles east of Hoh post office, approximately in the SE. $\frac{1}{4}$ sec. 15, T. 26 N., R. 13 W., 150 feet or more of poorly consolidated conglomerate is exposed. This conglomerate probably corresponds in age to the beds of similar clay and conglomerate of Pleistocene age noted in other parts of the area.

The rocks exposed in the shaft of the Lacy oil seep, situated about $2\frac{1}{2}$ miles northeast of Hoh post office, are reported to consist of soil, sandy clay, sand, gravel, and boulders of Pleistocene and Recent ages. The larger pebbles and boulders are a foot or more in diameter and increase in size with the depth of the shaft. Most of them are sub-angular or flat sided, suggesting glacial scouring. W. H. Abbott, who assisted in opening the shaft, stated that it was his opinion that when the water is removed from the shaft the maximum flow of oil is about 2 barrels a day. At the time this place was visited by the writer, in



The same distance farther downstream medium-bedded gray sandstone, dipping 63° NE. and striking N. 57° W., is exposed. Two hundred feet farther down the river sandstone similar in appearance to that last described dips 52° NE. and strikes N. 55° W. The last two dip and strike readings are very much alike and indicate that probably both were measured on the same fault block. At location J, on the north side of the river, near the mouth of a small creek near the center of sec. 26, T. 27 N., R. 12 W., gas is reported by the owner to be escaping from the edge of a circular spring of water. The water in this spring is said to have a milky-white color, like that at the Devils Mush Pot, a few miles farther up Hoh River, which is due to the action of gas in loosening and carrying up very fine sediment from the bottom of the inverted funnel-shaped hole.

At location K, about $1\frac{1}{2}$ miles farther upstream, on the south side of the river, near T. H. R. Schmidt's place, beds of massive sandstone and brownish chocolate-colored sandy shale, dipping 31° E. and striking N. 39° W., are exposed just below the mouth of a small stream that joins Hoh River from the south. This exposure, which consists of about 5 per cent shale and the remainder sandstone and sandy shale, is the only one along the river for a mile or more both up and down stream. Very small lenses of coal, which attain a maximum thickness of 2 inches and a maximum length of 6 inches, are included in a sandstone stratum about 4 feet in thickness. The coal, which has a bright luster, burns with a bituminous odor and yellow flame. A small, almost vertical fault, trending N. 65° E., cuts these rocks. The section measured at this place is as follows:

Section of rocks exposed at location K, near the center of sec. 25, T. 27 N., R. 12 W.

	Feet.
Sandstone, gray, massive, coarse	40+
Sandstone, brownish gray; contains a little coal.....	4
Sandstone, bluish gray and rusty in places, argillaceous.....	15
Sandstone, gray, massive, with thin beds of shaly sandstone which contains a little coal in small lenses at base ¹	45
Sandstone, grayish brown, thin bedded at base; contains thin lenses of conglomerate.....	75
Sandstone, gray, thin bedded, with a little sandy shale.....	40
Sandstone, gray, massive; contains thin lenses of coal at the top..	50
	269+

Rocks that may be exposed along Hoh River, between location K, near Schmidt's place, and location L, about $1\frac{1}{2}$ miles southwest from Spruce post office, on the south side of the river, were not examined, because on traversing the valley the trail which lies on the north side of the river and some distance from it was followed. The rocks over which the trail passes consist principally of clay, sand, and gravel,

¹ The lower part of this section is slightly faulted.

partly consolidated and partly loose, of Pleistocene and Recent ages. Along the trail from Schmidt's place to Spruce post office none of the older formations are exposed.

At location L, referred to above, a hard dark fine-grained medium-bedded sandstone, containing here and there near the top thin lenses of limestone, is exposed. Above the limestone the rocks consist of dark chocolate-brown iron-stained argillaceous sandstone, which has apparently been subjected to crushing forces, as it is now quite brittle and crumbles easily. The beds dip approximately 50° SE. and strike N. 40° E. At location M, about one-half mile farther east, in the vicinity of the mouth of Owl Creek, very hard dark fine-grained medium-bedded sandstone, with some dark hard fine-grained sandy shale in the western part of the outcrop, is exposed. It is rather difficult to obtain a reliable dip and strike reading at this place on account of the massiveness of the strata. However, the prevailing dip is about 75° NE. and the strike is N. 40° W. The Devils Mush Pot, described in detail on pages 29-30, and referred to in other parts of this paper, is situated at location N, about one-fourth of a mile farther northeast. It may be added here that the rocks surrounding the gas vent consist of gravel, sand, and clay of Recent age. As the "mush pot" is situated near the outcrop of the older rocks, at location M, and as this same formation outcrops to the east of this locality, it is reasonable to assume that the gas which escapes from this vent originates probably deep in the older rocks instead of those at the surface. In traversing the upper part of Hoh River above Spruce post office a recently completed trail, which lies on the north side of the river and in most places one-fourth to three-fourths of a mile from it, was followed, and hence no exposures were seen by the writer in this stream valley farther north than those just described in the vicinity of Spruce post office. It is reported that gas is escaping in small quantities at location O, which is a few hundred feet north of Hoh River and on the eastern edge of the area represented on Plate II (p. 78). This point, which is about 5 miles east of Spruce in the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 22, T. 27 N., R. 11 W., was visited by the writer, but no evidences of gas were noted.

It is believed, as has been stated in the beginning of the description of the rocks exposed along Hoh River, that many outcrops of rock in addition to those noted above can be seen along this stream, and that whenever more detailed work is to be done in this region it will be necessary for the geologist to traverse the river by means of a canoe and examine carefully every exposure, however small, as was done by the writer along the lower courses of Moclips, Queniult, Queets, and Clearwater rivers.

The strata exposed along the lower course of Hoh River between locations A and H are, with but little question, representative of the

"supposed Cretaceous" rocks, whereas those beds exposed in the prominent canyon of the Hoh River in secs. 27 and 28, T. 27 N., R. 12 W., and from this locality east to location M, near Spruce, probably belong to the Clallam formation, of Oligocene and Miocene age, described by Arnold.¹ It is possible that those beds exposed at locations F, G, and H in the vicinity of Elliott's place (formerly Pins post office) may belong to the same formation. As stated previously, it was Arnold's opinion that the rocks exposed in the hills south of Bogachiel River belong to the Clallam formation. The hills referred to constitute the divide separating the drainage of the Bogachiel from that of Hoh River, and at no place east of range 13 are they more than 4 miles from the Hoh.

Beds of Pleistocene age overlie the older formations unconformably and at one place along Hoh River (location C) bluish sandy clay, presumably of the same age, outcrops along the river bank. At no place along Hoh River did the writer note any evidence of "smell mud" and at but one locality (the Devils Mush Pot) is there any evidence of natural gas, except that reported at location J, on Billy Snell's land.

ROCKS EXPOSED ALONG BOGACHIEL RIVER.

The rocks along Bogachiel River were examined at only five localities. The river was not traversed and the points visited are places where rock outcrop or indications of oil or gas were reported.

At location A, on the south side of the river, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 27, T. 28 N., R. 14 W., about a mile southwest of the Wilson place, which is described in detail on page 30, "smell mud" is very plentiful in a comparatively recent landslide 75 to 100 feet above the river level. At a point about one-fourth of a mile upstream from location A 6 feet of gray sandstone, which contains some carbonaceous material underlain by sandy shale, is exposed. These beds dip 37° SE., strike N. 34° E., and constitute the only known exposure of the "supposed Cretaceous" rocks for a mile or more both up and down stream. At location B, on the opposite side of the river, nearly flat-lying beds of poorly consolidated sand, clay, and gravel, which are believed to be of Pleistocene age, are exposed for several hundred feet. At location C, near the center of sec. 35, T. 28 N., R. 13 W., just north of the place where the trail from Forks to Bogachiel crosses Bear Creek, a very poor exposure of yellowish-gray argillaceous sandstone overlain by yellow clay shows that the strata dip about 36° SE. and strike N. 30° E. Beds of sandstone are exposed at location D, at the point where the trail referred to above crosses Coon Creek, in the NW. $\frac{1}{4}$ sec. 26, T. 28 N., R. 13 W.

¹ Arnold, Ralph, Geological reconnaissance of the coast of the Olympic Peninsula, Wash.: Geol. Soc. America Bull., vol. 17, pp. 461-462, 1906.

At this locality beds of dark, resistant sandstone are exposed, but it was difficult to measure the dip and strike on account of the massive character of the rock. Apparently the rocks have a southeastward dip and seem to strike in the same general direction as the beds at location C, described above. Another exposure of rock was examined about one-half mile west of Morgan ranger station, at location E, in the NW. $\frac{1}{4}$ sec. 5, T. 27 N., R. 12 W. The rocks here consist principally of gray sandstone overlain by blue shale which have a general dip of about 39° E. and strike N. 5° W. Joints and fractures which have been filled with quartz or calcite are numerous in the sandstone.

The rocks exposed at location A, 2 or 3 miles above the mouth of Bogachiel River, probably belong to the "supposed Cretaceous" formation so well exposed along the coast south of Hoh Head.

The strata exposed at locations C, D, and E, in the vicinity of the Bogachiel post office, probably are of Oligocene and Miocene age and belong to the Clallam formation, as suggested by Arnold.

Beds of Pleistocene clay, sand, and gravel unconformably overlie the older rocks throughout the greater part of this region. They outcrop extensively along Bogachiel River at location B, near Wilson's place, 6 or 7 miles southwest of Forks.

ROCKS EXPOSED ALONG CALAWA RIVER.

The rocks on Calawa River were examined only at location A, on the south side of the river, in the southern part of sec. 35, T. 29 N., R. 13 W., about 3 miles northeast of Forks. At this place 300 to 400 feet of gray and brown sandstone, much broken by faults, is exposed. The rocks are principally massive, and on account of faulting the joints and bedding planes are so nearly alike that it was difficult to distinguish one from the other and to measure the true dip and strike. The prevailing dip seems to be 62° NE. and the strike N. 45° W. These rocks probably belong to the same formation as do those in the vicinity of Bogachiel to the south, namely, the Clallam formation, of Oligocene and Miocene age.

The Washington Oil Co. is drilling a well on the Anderson farm in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 9, T. 28 N., R. 13 W., about a mile south of Forks. In the latter part of March, 1914, the drill had penetrated to a depth of more than 1,600 feet. A general section is given below:

Driller's record of the Washington Oil Co.'s well on the Anderson farm near Forks.

	Thickness.	Depth.
	<i>Feet.</i>	<i>Feet.</i>
Soil, black.....	4	4
Sand, unconsolidated (much water).....	116	120
Shale, light.....	380	500
Shale, blue (showing of oil at base).....	450	950
Shale, brown.....	600+	1,550+

STRUCTURE.

GENERAL FEATURES.

The structure of the area represented on Plate II (p. 78) is characterized by a prominent anticline or possibly a monocline, the axis of which is situated some distance out in the ocean, extending in a general north-south direction in places, turning slightly to the northwest. The east flank of this anticline, which underlies the area under consideration, is crossed almost at right angles to its strike by several smaller anticlines and synclines. The general structure is indicated on the accompanying map (Pl. II) by dip and strike symbols, which almost invariably show that the rocks dip in general toward the east and strike in a north or northwest direction. The minor anticlines and domelike structures are also shown by dip symbols.

One of the most prominent of these minor anticlines crosses Queets River about $2\frac{1}{2}$ miles from the coast, extending northeast and southwest through the eastern part of sec. 35 and the northwestern part of sec. 36, T. 24 N., R. 13 W. The dips of the rocks on Clearwater River, a mile or more north of the present site of Clearwater post office, indicate that the same anticline that crosses Queets River near its mouth extends to that locality, but there it seems to be somewhat narrower than it is near the mouth of Queets River. A study of the dips and strikes farther up Clearwater River does not indicate that it continues for a great distance north of sec. 18, T. 24 N., R. 12 W. The writer is unaware of any gas or oil vents along this anticline.

There is evidence of another prominent, although narrow, anticline extending in the same general direction on the coast at the mouth of Cedar Creek, about $3\frac{1}{2}$ miles southeast of the mouth of Hoh River. This anticline seems to cross Hoh River a short distance east of Hoh post office. It is interesting to note that the Lacy seep, situated in the NW. $\frac{1}{4}$ sec. 11, T. 26 N., R. 13 W., is nearly on the projected axis of this anticline. "Smell mud" is plentiful on the coast near the mouth of Cedar Creek.

Another prominent anticline in "supposed Cretaceous" rocks cuts the coast just south of Hoh Head and like the two anticlines just discussed extends in a northeast direction. No evidence is at hand regarding its extent inland. The Jefferson Oil Co.'s seep and well are situated near the crest of this anticline. Oil-saturated rock is not known to exist along the coast on the upfold, but a little farther south, near location Z, it is plentiful.

As was pointed out by Arnold, the Queniult formation, which outcrops on both sides of the mouth of Queniult River along the coast for 2 miles, occupies a broad syncline. This syncline, to judge from dips and strikes along the coast and about 2 miles above the mouth of Queniult River, also trends in a northeast-southwest direction.

The structure of the beds of Pleistocene age is very simple. In most places they lie practically horizontal. At those localities in which these strata are somewhat inclined their disturbance is undoubtedly of recent date and is due probably to landslides and slumps, which in some places have produced buckling.

Evidences of other small anticlines are pointed out below in the description of the structure by districts. The description of the Pleistocene beds will be omitted in these detailed descriptions, as their structure has nothing to do with the accumulation of oil and gas.

COAST DISTRICT.

Between locations A and B there are no exposures of the older rocks except in the vicinity of location A, near Copalis Rock, where, as has been stated above, reliable dip and strike readings could not be obtained. Between locations D and E, in the vicinity of Point Grenville, much faulting has taken place in what is believed to be the old metamorphic rocks. Dip and strike readings and measurements of the inclination and direction of fault planes differ so widely that the more prominent features of the structure in this locality can not be shown on a map of the scale of Plate II. The principal fact of interest is, however, that between locations D and E lies an upfaulted block of metamorphic rocks, which is very much faulted and folded within itself.

The Queniult formation exposed between locations E and II, in the vicinity of the mouth of Queniult River, is in general a broad syncline, the axis of which extends in a northeast direction and which cuts the coast a short distance south of the mouth of Queniult River. It is doubtful if this formation has any important relation to oil or gas that may underlie these strata in the "supposed Cretaceous" beds. Between locations H and I, along the coast, there is evidence again of a comparatively narrow upfaulted block of "supposed Cretaceous" rocks. Northward from location I to the mouth of Raft River the "supposed Cretaceous" rocks strike in general north slightly east and dip east in almost every locality. At the mouth of Raft River a fairly reliable measurement shows that the beds dip about 53° NW. and strike N. 25° E. for a short distance. This narrow anticline is associated with "smell mud" along the coast, as is shown on Plate II (p. 78).

Flat-lying beds of Pleistocene age occupy the coast from location O to location Q with the exception of a very small area at the mouth of Kalaloch Creek. Northward from location Q to a point a short distance south of the mouth of Cedar Creek the general strike of the strata ranges from north to N. 18° E., the dip being generally eastward. A small anticline, described above, breaks the monotony of the gen-

eral eastward dip for about one-half mile north of the mouth of Cedar Creek, north of which point the older strata are entirely covered for some distance by flat-lying Pleistocene beds. In the vicinity of the mouth of Hoh River and to the northwest as far as location EE, about 1 mile north of Hoh Head, the strata are much disturbed by northeast-southwest anticlines and some still smaller folds and faults. Near the mouth of Hoh River there is evidence of an elongated dome extending in general east and west. Faulting has disturbed this structure at location A, on Hoh River. A mile or more northwest of location Z, on the coast, the prominent northeast-southwest anticline on which the Jefferson Oil Co.'s seep and well are situated dominates the structure. North of Hoh Head there are also indications of a minor anticline extending in a northwest direction, as suggested by a dip of 45° SW. and a strike of N. 65° W. at location DD, whereas there is a dip of 60° E. and a strike of N. 10° W. at location EE.

HUMPTULIPS RIVER BASIN.

The general dip of the strata along Humptulips River and the east fork of the same river between the village of Humptulips and location I, about 4 miles southeast of East Fork dam, is to the east. Beds exposed at location J, a short distance west of the contact between the sedimentary and igneous rocks, have a steep dip to the west. The dip and strike symbols on Plate II show the details of structure along Humptulips River better than any written description. The structure of the almost flat-lying beds of Pleistocene age on Camp No. 2 and Stevens creeks needs no further explanation than that shown on the map (Pl. II, p. 78) in addition to what has already been stated under the heading "General features" (p. 74).

MOCLIPS RIVER.

The beds exposed along the lower course of Moclips River outcrop in an anticline which trends in a northwest-southeast direction. The extent of this anticline in either direction is not known on account of the thick cover of Pleistocene beds, and for that reason the position and direction of the axis are shown only near the stream.

QUENIULT RIVER BASIN.

The description of the structure of the rocks exposed along Queniult River and Queniult Lake will necessarily be brief because the beds exposed in this part of the field are principally of Pleistocene age and in general are flat-lying. The rocks in the vicinity of Higley's hotel, in sec. 8, T. 23 N., R. 9 W., at Onion Rock, and the two exposures farther west presumably belong to the "old metamorphic series," as do also the rocks exposed at Burnt Hill in secs. 1 and 12, T. 22 N., R. 11 W. As stated before in this report, it is believed

that the rocks exposed at Burnt Hill are greenstone, whereas those in the vicinity of Higley's hotel on the north side of the lake, which in places seem to stand almost vertical, are believed to be in part sedimentary.

The strata outcropping at locations A, B, and D, near the mouth of Queniult River, and at location I, about 10 miles from the coast, dip in general to the east. They are broken in places, as has been stated before in the detailed description of location D, on page 30. Without doubt the beds at locations A, B, and D belong to the Queniult formation and possibly those outcropping at location I also. There is a probability, however, that the rocks at location I may be "supposed Cretaceous," in which case a fault or fold must exist to the southwest and west of this exposure. If it is an upfold the axis of the anticline or monocline, on the north flank of which this outcrop is situated, must necessarily lie to the south of this locality, but no information is at hand regarding its exact position.

QUEETS RIVER BASIN.

The outcrops of rock on which dip and strike readings were measured along Queets and Clearwater rivers and the lower courses of Salmon River and Matheny and Sams creeks are much more numerous than are the exposures in any of the other regions examined. The prevailing dip of the rocks, as a glance at the dip and strike symbols on Plate II indicates, is in general to the east. However, at localities where faulting and folding have disturbed the strata, the strike of the beds as well as the direction of dip differs considerably. As stated on page 74, the principal anticline in this basin seems to cross Queets River about $2\frac{1}{2}$ miles above its mouth. The evidence of an anticline on Clearwater River in the vicinity of locations D and E is fairly conclusive, but it is questionable if the anticline noted near the mouth of Queets River and the one on Clearwater River in the vicinity of locations D and E are the same, and it would be unwise to definitely correlate them. A correlation, however, is suggested on account of the relative positions of these two sections of anticlines, as the strike of the rocks near the mouth of Queets River at locations A, B, and C shows that it would cross Clearwater River, if continued in the same direction, at approximately the position where the anticline on Clearwater River exists. More detailed work along Elk Creek and tributaries of Elk Creek in secs. 24 and 25, T. 24 N., R. 13 W., would undoubtedly furnish conclusive evidence regarding this point if these streams have eroded through the Pleistocene cover. Between location L on Queets River and location D on Sams Creek, a distance of about 14 miles as the river runs, no outcrops of the "supposed Cretaceous" or Tertiary formations are exposed. This distance is sufficient for several small narrow anti-

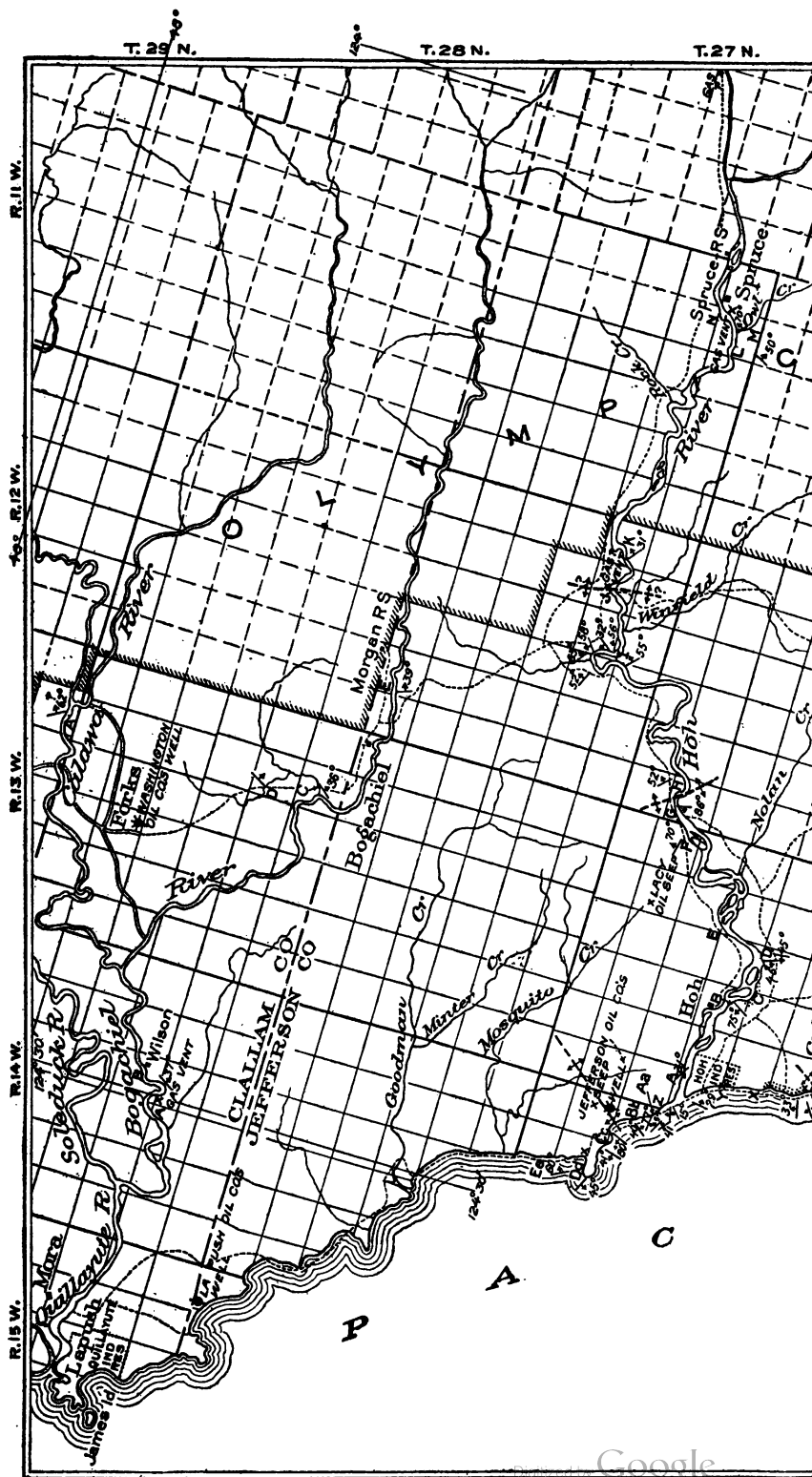
clines, but no evidence is at hand, even taking into consideration the beds exposed in the canyon of Matheny Creek, that there are any such favorable structures for the accumulation of oil or gas. As noted on page 63, the prevailing dip of the rocks in Matheny Creek canyon is to the east, which corresponds exactly with the prevailing eastward dip of the rocks along all the principal streams in the area represented by Plate II.

Dip and strike measurements taken in Salmon River canyon between locations A and E suggest the existence of an elongated dome or anticline, which are favorable structures for the accumulation of oil and gas. As the strata here are broken by minor faults, and as the same beds on Queets River about a mile to the north have persistent eastward dips, it is very questionable if the structure here is really favorable.

Although the dip and strike of the rocks along Clearwater River indicate that the structure is very complex, yet the more reliable measurements show that the rocks have a general eastward dip and that prominent anticlines are absent. Wherever westward dips occur they are usually due to the presence of faults and folds which undoubtedly do not extend to a great depth below the surface and hence would have but little effect in constituting reservoirs for the accumulation of oil and gas.

HOH RIVER BASIN.

Dip and strike readings measured at the mouth of Hoh River, although very meager, suggest that a narrow anticline or possibly a small dome is situated here. This structure apparently does not extend far inland or far north or south from the mouth of Hoh River. About one-half mile southeast of Hoh post office "supposed Cretaceous" beds strike approximately N. 25° E. and dip about 75° NW. At the mouth of Cedar Creek there is evidence of a comparatively narrow anticline which has the same general trend. The axis of this anticline projected inland from the coast would cross the river near the point where the strata were measured in sec. 21, T. 26 N., R. 13 W., and if projected still farther north would lie near the Lacy seep. The position of the axis of the anticline north of Hoh River as above indicated is only approximate, but it seems that this assumption is fairly reasonable. Just east of Elliott's ranch the dip and strike readings indicate the existence of a small anticline which trends in a general northwest-southeast direction. The rocks are faulted slightly and the apparent anticline may not constitute a favorable structure. The rocks farther up Hoh River dip in general to the east, as they do along Queets and Clearwater rivers. The structure of the rocks exposed at the conspicuous canyon on Hoh River, at location I and to the west, and those



outcropping at location K, southeast of Schmidt's house, on the south side of Hoh River, suggest that a northwest-southeast anticline may extend through this general region, the axis of which may cross the river in the vicinity of the gas vent reported by Billy Snell at location J, on the north side of Hoh River, approximately in the center of sec. 26, T. 27 N., R. 12 W. The rocks exposed at locations L and M, about a mile west of the Devils Mush Pot, near Spruce post office, have a general eastward dip, which suggests that this gas, if it is related structurally to the rocks exposed at locations L and M, must be escaping at some distance down the east flank of an anticline, the main axis of which may cross the river in the vicinity of location J, at the point where gas is escaping near Billy Snell's place.

QUILLAYUTE RIVER BASIN.

Very little information regarding structure was obtained in this locality. As noted by the dip and strike symbols at locations A, B, C, D, and E, on and near Bogachiel River, and location A on Calawa River, about $2\frac{1}{2}$ miles northeast of Forks, the prevailing dip of the rocks is to the east, as at nearly all other localities in this field. Most of the points where the readings were taken are so widely separated that there is room for one or more small anticlines to be present in the intervening space, but the writer has no evidence of their existence. Further detailed work along these streams and the streams to the north will undoubtedly yield valuable information regarding the position of any anticlines that may be present.

RELATION OF STRUCTURE TO ACCUMULATIONS OF OIL AND GAS.

In regions where the strata are saturated with water ("wet"), as is the case in this field, oil and gas collect usually under anticlines or domes that are capped by some impervious stratum. On the other hand, in regions where the strata are comparatively "dry" the oil tends to collect in synclines or basins. The principle on which this action takes place is quite simple. Wherever open porous rocks contain water and oil disseminated through the mass there is a tendency for the water, being the heavier, to collect below and thus force the oil to occupy a position above it. If, however, the rocks are thoroughly saturated, there will be a general migration of the globules of oil upward through the strata until they reach the surface of the earth or until their progress is stopped by the presence of rocks like clay, shale, and dense sandstone, which are almost impervious to oil. If the porous stratum and the impervious cover are flat-lying probably there will be no large accumulation of oil, but if they are inclined slightly the oil will continue to migrate up the rise at or near the base of the impervious stratum until it reaches

the upper limit of water saturation, or the surface of the earth and escapes in an oil spring or seep. If the structure is that of a dome or anticline the oil will collect in the porous rock directly underlying the impervious cap in the top of the anticline (except where gas is associated with the oil, in which case the gas will occupy the highest position) and remain there until it can escape to the surface through natural vents, such as seeps and fault planes, or artificial openings (drill holes). It is also true that if oil and gas are associated in the same rocks, as is usually the case, the gas, being lighter than the oil, will naturally occupy the crest of the anticline or apex of the dome underlying the impervious stratum. If the rocks are "dry" the disseminated oil particles acted upon by the force of gravity tend to migrate downward. If the structure is that of a syncline or basin underlain by an impervious stratum the oil will collect in the depression.

In this discussion the simplest condition, that in which the rock containing the oil is a homogeneous mass overlain or underlain by a stratum impervious to oil, is assumed. It is believed that where the conditions are more complex, as where the oil is included in a shale or compact thin sandstone containing lenses of coarser sandy material and the rocks are fairly saturated with water, the oil will be forced into the rock whose pore spaces are larger, owing to the differential capillary attraction of water and oil.

CONCLUSIONS.

The writer does not predict that oil will be found in commercial quantities in this field, but he firmly believes that it is a region worthy of the attention of oil operators.

The report does not attempt to describe the stratigraphy and structure of all the rocks exposed in the area represented by Plate II, but it does set forth all data collected in this field during the two months' reconnaissance.

It is significant that all places where oil is escaping from the surface of the earth, either in seeps or in oil-saturated sandy clay, and the principal places where gas is escaping are situated in that part of the field where the older "supposed Cretaceous" and Tertiary rocks are exposed. It is believed that the source of the gas at the Garfield gas mound is not in the Quenilt formation, through which it issues to the surface, but in the underlying "supposed Cretaceous" formation. The gas escaping in Quenilt Lake issues from a place where marsh gas is naturally expected to occur, namely, at the mouths of streams which have carried and buried and are continuing to carry and bury large quantities of vegetation, the decomposition of which could easily explain the large quantities of escaping gas. As this gas

was not analyzed, it is impossible to state definitely whether it is natural gas or marsh gas. The location of the vents suggests marsh gas.

In this field, as has already been pointed out, the oil seeps and occurrences of "smell mud" are firmly believed to be situated near the crests of anticlines. The gas vents are not similarly located because, as has been shown, the gas escaping at the Devils Mush Pot, near Spruce post office, on Hoh River, is certainly not associated with the crest of an anticline of the rocks which outcrop just to the west. It is also true that the gas escaping at the Garfield gas mound is not situated near the crest of any known anticline. However, it may be situated near the crest of an anticline of the underlying "supposed Cretaceous" rocks, which are believed to be unconformably overlain by the Quenilt and younger formations. As the rocks of this field, which lies in that part of the United States where the annual rainfall is greatest, are undoubtedly well saturated with water, and as the principal oil seeps are situated near the crests of anticlines, it seems advisable for those desiring to exploit the oil and gas resources of the region to drill in the vicinity of the crests of an anticline rather than in a syncline or where monoclinal dips prevail.

The structure of rocks along the various river basins have been considered by districts. That discussion, together with dip and strike symbols and the lines representing axes of anticlines shown on the map (Pl. II), should be a guide in a very general way to those contemplating drilling. It should be kept in mind, however, that the presence of favorable structures, such as anticlines and domes, is not absolute proof that oil will be found. It is fairly safe to assume that if the oil is not discovered where the structure is favorable the chances are very remote that it will be discovered where the structure is positively unfavorable.

The discovery in this region and in commercial quantities of oil similar to that issuing from the seeps near Hoh Head would undoubtedly prove to be a great boon to the Olympic Peninsula in that it would be a means of opening this comparatively unknown region to settlement. From the rainfall, the character of the soil, the numerous water-power sites, and other natural advantages, it seems quite probable that this region may in time furnish homes for thousands.



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581—C

THE MOORCROFT OIL FIELD AND THE
BIG MUDDY DOME, WYOMING

PAPERS BY

V. H. BARNETT

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—C



WASHINGTON
GOVERNMENT PRINTING OFFICE

1914

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THE MOORCROFT OIL FIELD, CROOK COUNTY, WYOMING.

By V. H. BARNETT.

INTRODUCTION.

The Moorcroft oil field lies 12 miles north of the town of Moorcroft on the Chicago, Burlington & Quincy Railroad. The presence of oil in this field has been known for at least a quarter of a century and many wells have been drilled in the hope of developing a commercial pool, but in only seven of these wells has oil been found in appreciable amounts. The present investigation, made in June, 1913, followed a withdrawal of the land from entry pending examination, and the object of the investigation was to determine, as far as might be, the possibilities of the field by a study of the geologic structure, the various formations involved, and the conditions under which the accumulation of oil has taken place. The results of the work are not on the whole encouraging to further development of the field.

The first operations in the field, as shown by Territorial Geologist Ricketts's report,¹ began prior to 1888. He stated that oil of high specific gravity was pumped from one well and collected from over a dozen springs, and was "transported to mining towns in the Black Hills, where it commanded a ready sale as a lubricating oil at a price of \$28 per barrel." The well, owned by the Wyoming Standard Oil Co., was 300 feet deep and produced 5 barrels of oil a day. Some of the springs were said to have yielded 20 gallons a day, but this is probably excessive, as Ricketts says that the spring in the SE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., when first cleaned out yielded about 90 gallons of oil a month. The oil at this spring collected on top of the water and was secured with a dipper.

Different companies have drilled in the Moorcroft field at various times since 1887, until at present there are about 60 holes scattered throughout the field.

The only wells which have yielded enough oil to warrant capping and attaching pumps are seven that form a small group in sec. 34, T. 52 N., R. 67 W. These, if pumped, would probably yield for a short time about 5 barrels each a day. They are owned by the Butte Crude Petroleum Co., a Montana corporation, which some years ago installed a pumping plant and wooden tanks.

¹ Ricketts, L. D., Annual report of the Territorial geologist to the governor of Wyoming, p. 43, 1888.

The Moorcroft oil field, including parts of Tps. 50 and 51 N., Rs. 66 and 67 W., and T. 52 N., R. 67 W., as shown in figure 2, lies for the most part in an open plain bordered on the east by a ridge, which rises from 200 to 400 feet above the main part of the field. On the west there is also higher land, a more or less distinct escarpment rising to about the same level as the ridge on the east. The ridge and the escarpment are parallel, extending north and south. There are other smaller ridges near the west foot of the high ridge and parallel to it. The valley of Belle Fourche River, which with its tributaries drains the field, is broad and flat, except in T. 51 N., R. 66 W., where

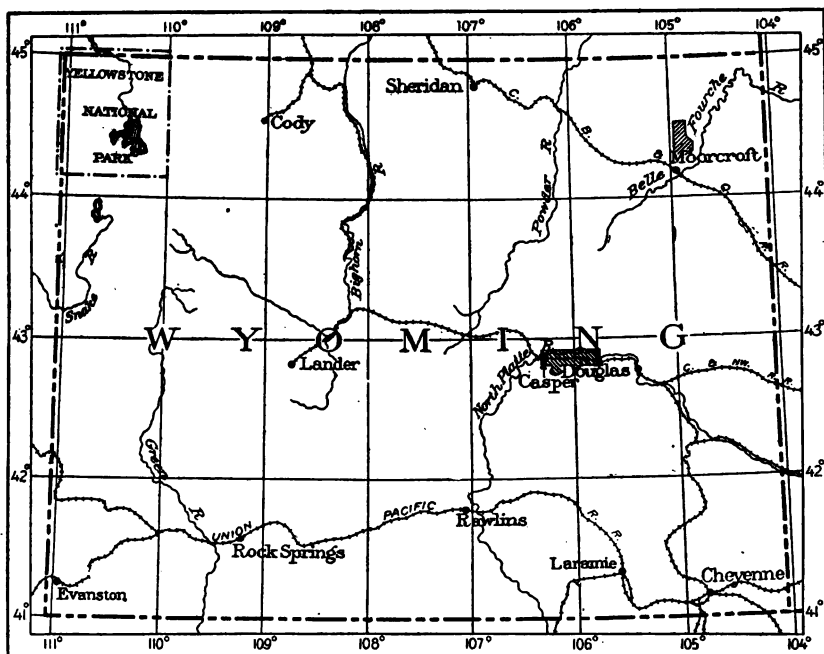


FIGURE 2.—Map of Wyoming showing the location of the Moorcroft oil field and the Big Muddy dome.

it flows between more or less precipitous bluffs which rise abruptly a short distance back from the stream. The high ridge on the east side of the field is trenched by deep ravines and in some places dissected into badlands.

The elevation of the field ranges from about 4,050 feet above sea level on Belle Fourche River, in sec. 29, T. 51 N., R. 66 W., to 4,650 feet on the ridge in sec. 36, T. 52 N., R. 67 W., the average elevation being about 4,200 feet above sea level.

Certain small areas in the Moorcroft field are cultivated and fair crops of grain, alfalfa, and timothy are raised. Some irrigation is done, especially along Belle Fourche River, but up to June, 1913, only a small part of the irrigable land was in use. The valley of

Belle Fourche River, in places over 2 miles wide, is for the most part uncultivated and covered by sagebrush and native grasses. If an adequate irrigation system could be established it might well be put under cultivation. Considerable success also is attending cultivation without irrigation, and such farms are at present as numerous as those which are irrigated. A large part of the Moorcroft field is suitable only for grazing and a few small tracts yield a sufficient growth of grass to be cut for hay. Local areas along the eastern border of the field are covered by pine trees, some of which are sufficiently large for building material.

Fuel for domestic use consists of wood from the timbered areas in the eastern part of the field and of coal shipped from places along the Chicago, Burlington & Quincy Railroad or hauled by wagon from mines in the coal field southwest of Moorcroft.

The principal water supply is obtained from Belle Fourche River, which crosses the southern part of the field in a general northeasterly course, and from a number of springs of fairly good water along the foot of a ridge which extends across the east side of the field from northwest to southeast. Water is also obtained in very shallow wells in the vicinity of this ridge and some of the borings for oil have developed flowing wells of water, all of which are of low pressure.

ACKNOWLEDGMENTS.

The writer was assisted in the field work by Frank Elliott, for whose aid he desires to express his appreciation. Mr. B. M. Campbell, a resident of the field, rendered valuable assistance. Mr. W. I. Lippincott, of the Butte Crude Petroleum Co., Butte, Mont., and Mr. J. H. Russell, of the Mineral Oil Co., supplied information in regard to the wells drilled by their respective companies. To Mr. Charles Louis credit is also due for information regarding developments in the field.

METHOD OF FIELD WORK.

The Moorcroft field was mapped on a scale of 2 inches to the mile by means of a plane table and telescopic alidade, the township being the unit represented by each field sheet. A complete system of triangulation was established covering the field, and the stations of this system served the purpose of horizontal and vertical control and supplied the means of tying together in the final compilation of the map the different plane-table sheets. In beginning the primary control or triangulation a base line 7,300 feet in length was measured by stadia along a fairly level stretch between two intervisible points, the line extending from well No. 44 in sec. 27, T. 52 N., R. 67 W., in a northwesterly direction to a prominent point in sec. 22. From this line as a base a system of triangulation was carried over the field and supplemented by stadia traverses from triangulation stations.

The triangulation system was tied by a stadia traverse to a bench mark, established by the topographic branch of the United States Geological Survey, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 7, T. 52 N., R. 66 W. (see Pl. III, p. 104), and from this bench mark the altitudes of the various triangulation stations and stadia points were calculated.

The map (Pl. III) was assembled after returning to the office by joining the individual plane-table sheets, using the points common to two or more of them.

THE OIL.

SEEPS AND WELLS.

At several localities in the Moorcroft field oil finds its way to the surface in the form of seeps or springs.

In the SE. $\frac{1}{4}$ sec. 2, T. 51 N., R. 67 W., at a small spring seeping from the shale and sandstone of the Fuson shale¹ oil collects on the surface of the water; in the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., a very small amount of oil occurs in a ravine in the sandstone member of the Graneros shale; in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., there is a spring of water on the surface of which oil collects in sufficient quantity to be dipped up with a ladle; and about one-quarter of a mile farther north, in the next ravine, at another spring of water, oil collects in very small quantities. In the sandstone member of the Graneros shale exposed in a ravine in the SE. $\frac{1}{4}$ sec. 22, T. 52 N., R. 67 W., there is oil in sufficient quantity to give a brownish color to the rock and impart a distinct odor of petroleum. Oil also seeps to the surface in three of the old drill holes along the west flank of the anticlinal ridge, as follows: Well No. 4, in sec. 36, T. 51 N., R. 67 W.; well No. 14, in sec. 12, T. 51 N., R. 67 W.; and well No. 30, in the NE. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W. Oil is obtained at a depth of about 600 feet from six wells in the NW. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., where it occurs either in the sandstone member of the Graneros shale or in the Mowry shale member of the Graneros and is reported to have been struck at a depth of about 600 feet.

Of the 65 seeps and wells described in the following pages, 3 are oil springs, 21 are shallow holes which should not be considered wells, and 41 are wells which are perhaps fair tests for oil at the localities where they were drilled. Of these 41 test holes 15 are reported to have struck "showings" or small quantities of oil. One well is reported to have yielded a small amount of gas and 4 wells gave flowing water. All the wells in the field but 7 have been abandoned as oil wells.

In the following description the wells and seeps of the Moorcroft field are taken up by number, each number in the text having a corresponding number on the map. The most southerly well in the field

¹ For descriptions of formations see pp. 94-104.

is No. 1 and wells and seeps are numbered in consecutive order northward, so that the highest numbers are in the northern part of the field and the lowest ones in the southern. These numbers have no reference to the order in which the wells were drilled or to the companies drilling them.

Well No. 1.—Well No. 1 is located on the flat along Wind Creek in sec. 12, T. 50 N., R. 67 W. At the time of the writer's visit (June, 1913) a Star rig was at the place and drilling had been started by the Wyoming Fuel & Oil Co., but operations had been stopped, apparently for repairs. The well has since been abandoned. The depth was not ascertained. The altitude of the surface is 4,110 feet.

Well No. 2.—Well No. 2, located in sec. 1, T. 50 N., R. 67 W., is probably the well mentioned by Darton¹ as the "Rapid City No. 1." Its depth is given by that author as 1,300 feet. At present the only evidence of the well is blue clay on the surface, a slight depression, and some old timbers strewn about. The altitude of the surface is 4,100 feet.

Well No. 3.—Well No. 3 was drilled in the spring of 1913 by the Mineral Oil Co. and according to a statement of J. H. Russell, field manager, no oil was obtained. As shown on the map (Pl. III) the top of the well is below the oil-bearing sandstone in the lower part of the Graneros shale, so that the only probable oil-bearing rocks which the well could enter are the Dakota and Lower Cretaceous formations.

Log of well No. 3, sec. 5, T. 50 N., R. 66 W.^a

[Altitude of surface, about 4,230 feet.]

Probable formation.	Driller's description of the rock.	Content.	Thick- ness.	Depth.
			<i>Feet.</i>	<i>Feet.</i>
Graneros shale.....	Black shale.....		156	156
Dakota sandstone.....	Sand.....	Water...	40	196
Fuson shale.....	Black shale.....		109	305
Lakota sandstone.....	Sand.....	Water...	45	350
Morrison shale.....	Black shale.....		110	460

^a This log is taken in part from a report by L. W. Trumbull, State geologist of Wyoming, on the Moorcroft oil field (in press).

Well No. 4.—Well No. 4 is located in sec. 36, T. 51 N., R. 67 W., and is probably the "Northwestern No. 2" of Darton,² 800 feet deep. According to a statement of Mr. B. M. Campbell, an old driller, some oil was struck. The well starts in the upper part of the Dakota sandstone and probably goes down nearly to the Sundance formation (Jurassic). At the time of the writer's visit (June, 1913) a little oil was standing on top of the water in the depression surrounding the drill hole. The altitude of the surface is 4,090 feet.

¹ Darton, N. H. Geology and water resources of the northern portion of the Black Hills and adjoining regions in South Dakota and Wyoming: U. S. Geol. Survey Prof. Paper 65, p. 95, 1909.

² Loc. cit.

Assessment wells.—At locations 5, 6, 7, 11, 12, 21, 26, 40 to 43, inclusive, 45, 46, 53 to 57, inclusive, 59, 60, and 62 very shallow holes have been drilled, the deepest probably not over 125 feet and most of them much less. A number of these were put down in 1913 and some were cased with "down spout" (tin tubing about 4 inches in diameter) at the time of the writer's visit. Some of these shallow wells apparently were drilled by the use of a spring pole and a tool similar to a post-hole digger, as the material on the dump pile was in cylindrical chunks 6 inches in diameter.

Well No. 8.—Well No. 8 is located in sec. 21, T. 51 N., R. 66 W., in the valley of Eggy Creek, a small tributary of Belle Fourche River. This well was drilled in 1904 and is reported to be 1,650 feet deep. A standard rig was used and some of the timbers were still on the ground at the time of the writer's visit. The well starts in the Fuson shale, and the red material on the surface indicates that it may have penetrated the Spearfish formation of probable Triassic age which outcrops farther east in the Black Hills.¹ The well was cased with wooden casing, which in June, 1913, was open and filled with water within 40 feet of the surface. The altitude of the surface is 4,100 feet.

Well No. 9.—Well No. 9 is located in sec. 24, T. 51 N., R. 67 W., and at the time of the writer's visit was still cased, the casing projecting 4 feet above the surface of the ground. The well was open and filled with water within about 45 feet of the surface. The altitude of the surface is 4,100 feet.

Well No. 10.—Well No. 10, in the SW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 24, T. 51 N., R. 67 W., was drilled a number of years ago by the Monumental Oil Co. with a standard rig and is about 300 feet deep. Part of the timbers of the rig were still on the ground at the time of the writer's visit and the well was used by a near-by ranchman as a stock well. He obtains the water in a bucket 7 feet long and 4 $\frac{1}{2}$ inches in diameter, fitted with a valve in the bottom, which was lowered by a windlass into the casing. Water stood in the casing within about 40 feet of the surface of the ground and is of good quality. The well is located below (or east of) the outcrop of the main oil-bearing sandstone, so that the probabilities of finding oil were very poor. The altitude of the surface is 4,110 feet.

Well No. 13.—Well No. 13 is located in the SE. $\frac{1}{4}$ sec. 7, T. 51 N., R. 66 W., on the east side of the anticlinal ridge. The only evidence at the time of the writer's visit that a well had been drilled here was a hole in the ground and some old logs lying about the dump pile. It is reported to have been drilled by the Monumental Oil Co. to a depth of 700 feet and to have shown no evidence of oil. The altitude of the surface is 4,350 feet.

¹ Darton, N. H., and O'Harra, C. C., U. S. Geol. Survey Geol. Atlas, Aladdin folio (No. 128), 1905.

Well No. 14.—Well No. 14, in the SW. $\frac{1}{4}$ sec. 12, T. 51 N., R. 67 W., is abandoned. In a depression surrounding the old casing there was water at the time of the writer's visit, and on its surface a thin film of oil had collected. The top of the well (altitude 4,180 feet) is below the base of the oil-bearing sandstone of the Graneros shale, so that the small amount of oil which collects on the surface of the water probably seeps from the Dakota sandstone or underlying rocks.

Well No. 15.—Well No. 15, in sec. 11, T. 51 N., R. 67 W., was drilled a number of years ago by the Butte Crude Petroleum Co. to a depth of 440 feet. Apparently little or no oil was encountered, for the casing was drawn and the well abandoned. The altitude of the surface is 4,150 feet.

Well No. 16.—Well No. 16, in sec. 11, T. 51 N., R. 67 W., was drilled a number of years ago by the Butte Crude Petroleum Co. to a depth of 550 feet. Flowing water was obtained, and after the metal casing was drawn a ranchman drove in a casing of boards, which for a time permitted the flow of water. At present, however, the position of the well is indicated only by a mud hole. The altitude of the surface is 4,120 feet.

Well No. 17.—Well No. 17, in sec. 1, T. 51 N., R. 67 W., was drilled a number of years ago by the Butte Crude Petroleum Co. to a depth of 700 feet. No oil was obtained, and at the time of the writer's visit the only evidence of a well having been drilled here was the hole from which the casing had been drawn and a pile of blue clay on the surface. The altitude of the surface is 4,425 feet.

Well No. 18.—Well No. 18, in sec. 1, T. 51 N., R. 67 W., was drilled a number of years ago by the Butte Crude Petroleum Co. to a depth of 1,280 feet, but a set of tools was lost in the well and operations ceased. No oil is reported to have been found. The altitude of the surface is 4,450 feet.

Locality No. 19 (Bird Oil Spring).—At locality No. 19, in the SE. $\frac{1}{4}$ sec. 2, T. 51 N., R. 67 W., there is a small spring where oil collects on the surface of the water. Birds coming here to bathe get the oil on their feathers and are unable to fly away. Many of these birds never get out of the spring. Because of this fact the spring is known as the Bird Oil Spring. At the time of the writer's visit (June, 1913) there were no less than a dozen carcasses in and about the spring and the bottom was covered with bones of birds. There was just enough oil to make a thin coating over the surface of the water. Birds that get only a little oil on them are able to hop away, and the rocks and sticks and ground around the spring are stained with the oil. The oil seeps from a sandstone in the Fuson shale. In the side of the draw a little above the spring there is a bed of very tough impure asphalt about 8 inches thick, a sample of which was analyzed in

the laboratory of the United States Geological Survey by David T. Day. Mr. Day states that it "contains $17\frac{1}{2}$ per cent of oil, fairly soluble in ether. The oil, after extraction, shows 8 per cent of asphalt." The altitude of the spring is 4,330 feet.

Well No. 20.—Well No. 20, in the SW. $\frac{1}{4}$ sec. 2, T. 51 N., R. 67 W., is a shallow well drilled about 25 years ago. The well has long since been abandoned, hence it is probable that no oil was found. The altitude of the surface is 4,190 feet.

Well No. 22.—Well No. 22, in the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 3, T. 51 N., R. 67 W., was drilled in 1905 by Mr. Carnahan to a depth of about 500 feet. No oil is known to have been found in the well. When first visited by the writer in 1911 the only indications of the well were some pieces of rope and the blue clay brought up by the drilling. The altitude of the surface is about 4,125 feet.

Well No. 23.—Well No. 23, in the NE. $\frac{1}{4}$ sec. 3, T. 51 N., R. 67 W., was drilled a number of years ago to a depth of 220 feet and is said to have produced enough gas to flame 5 feet high. There is little evidence of the well on the ground at the present time. The altitude of the surface is about 4,150 feet.

Well No. 24.—Well No. 24, in the NE. $\frac{1}{4}$ sec. 3, T. 51 N., R. 67 W., was drilled in 1905 by Mr. Conway and yielded flowing water until the casing was pulled. It is located a few hundred feet northwest of well No. 23. The altitude of the surface is about 4,150 feet.

Well No. 25.—Well No. 25, in the NE. $\frac{1}{4}$ sec. 3, T. 51 N., R. 67 W., was drilled 25 years ago and yielded oil, which was freighted to Deadwood and sold at \$1 a gallon. In June, 1913, it was difficult to find the location of the well. The altitude of the surface is about 4,150 feet.

Well No. 27.—Well No. 27, in the NW. $\frac{1}{4}$ sec. 36, T. 52 N., R. 67 W., was drilled in the spring of 1913 by the Mineral Oil Co. and is 810 feet deep. No oil was found, but water sufficient for drilling was encountered at 790 feet. The well is situated on the crest of an anticline and starts in the Dakota sandstone. It probably enters rocks of Jurassic age near the bottom. The altitude of the surface is about 4,630 feet.

Well No. 28.—Well No. 28, in the SE. $\frac{1}{4}$ sec. 35, T. 52 N., R. 67 W., is an old well probably put down about 25 years ago. It was drilled by a standard rig, some of the old timbers of which were still on the ground at the time of the writer's visit. The well was without casing of any kind. The altitude of the surface is about 4,250 feet.

Well No. 29.—Well No. 29, in the SE. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled by the Butte Crude Petroleum Co. a few years ago. It is 550 feet deep and flows a constant stream of water about one-half inch in diameter. The well is used as a stock well, having been cased and fitted with a small pipe, which conducts the water into a wooden tank. No oil was reported. The altitude of the surface is 4,180 feet.

Well No. 30.—Well No. 30, in the NE. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled several years ago by the Butte Crude Petroleum Co. and is 1,050 feet deep. Some oil was struck in the first 15 feet and a little oil is reported to have been found at 285 feet. This well is located just above the outcrop of the oil sand of the Graneros shale, the outcrop being in many places saturated with oil. At the time of the writer's visit in June, 1913, there was no casing in the well, but the hole remained open and water stood at a depth of 25 feet. A tin can lowered to the water brought up clear water with a very small amount of oil floating on it. The altitude of the surface is 4,290 feet.

Well No. 31.—Well No. 31, in the NW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled several years ago by the Butte Crude Petroleum Co. to a depth of 550 feet. No oil is known to have been found but water was apparently obtained, as the casing was left in the well, which is rigged with a pump. The altitude of the surface is 4,230 feet.

Wells Nos. 32 to 36, inclusive.—Wells Nos. 32 to 36, inclusive, in the NW. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., were drilled a few years ago by the Butte Crude Petroleum Co. They are each about 615 feet deep and would yield a small quantity of oil by pumping, probably from 3 to 5 barrels daily for a short time. The company a few years ago installed a stationary engine and built three wooden tanks each with a capacity of 250 barrels. The five wells still had pump jacks attached at the time of the writer's visit in June, 1913, and one (No. 35) was rigged so that it could be pumped by hand. A sample obtained in this way from this well was analyzed by David T. Day, of the United States Geological Survey. (See analysis No. 1, p. 94.) The altitude of the surface at these wells is about 4,200 feet.

Well No. 37.—Well No. 37, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled some years ago by the Butte Crude Petroleum Co. to a depth of 830 feet. The casing was pulled and the well abandoned. The altitude of the surface is about 4,230 feet.

Well No. 38.—Well No. 38, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled some years ago by the Butte Crude Petroleum Co. to a depth of 830 feet. This well, with five others, Nos. 32 to 36, have pump jacks attached. The altitude of the surface is 4,230 feet.

Well No. 39.—Well No. 39, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 34, T. 52 N., R. 67 W., was drilled some years ago by the Butte Crude Petroleum Co. to a depth of about 830 feet. A small amount of oil is reported to have been obtained in this well. At the time of the writer's visit the casing was still in the well and was plugged with a piece of wood. The altitude of the surface is 4,230 feet.

Well No. 44.—Well No. 44, in the SE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., was drilled a few years ago by Mr. Vandersall, the ground having been leased from the Butte Crude Petroleum Co. A set of drilling tools and

the casing were left in the well. The altitude of the surface is 4,210 feet.

Locality No. 47.—At locality No. 47, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., there is a spring, locally known as the Park Oil Spring, in which the oil collects and may be dipped up with a ladle. The oil burns readily with a crackling sound due to water associated with it. The altitude of the surface is 4,260 feet.

Well No. 48.—Well No. 48, in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., was drilled in 1911 by the Butte Crude Petroleum Co. to a depth of 130 feet. A small quantity of oil was obtained, but the casing was drawn and the well abandoned. The altitude of the surface is 4,250 feet.

Locality No. 49.—At locality No. 49, in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., there is an old oil seep. A hole has been dug about 4 feet square in the bottom of a draw and walled with boards. At the time of the writer's visit water was standing in this excavation and the only evidence of oil was the stain on the board walls. The altitude of the seep is 4,265 feet.

Well No. 50.—Well No. 50, in the SE. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 27, T. 52 N., R. 67 W., was drilled in the spring of 1913 by the Mineral Oil Co. to a depth of 440 feet. A little oil is reported. The casing was drawn and the well abandoned. At the time of the writer's visit water was seeping from the hole. The altitude of the surface is about 4,240 feet.

Well No. 51.—Well No. 51, in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 28, T. 52 N., R. 67 W., was drilled in 1904 by E. P. Clark to a depth of 950 feet. The casing has been drawn and the well abandoned. The altitude of the surface is 4,315 feet.

Well No. 52.—Well No. 52, in the SE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 28, T. 52 N., R. 67 W., was drilled in 1904 by E. P. Clark to a depth of 1,240 feet. The casing has been drawn and the well abandoned. The altitude of the surface is 4,350 feet.

Well No. 58.—Well No. 58, in the NW. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 22, T. 52 N., R. 67 W., was drilled in the spring of 1913 by the Mineral Oil Co. to a depth of 680 feet. Water was struck in this well and a showing of oil is reported. The altitude of the surface is 4,300 feet.

Well No. 61.—Well No. 61, in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 21, T. 52 N., R. 67 W., was drilled a number of years ago with a standard rig and is said to be 1,100 feet deep. The casing has been pulled and the well abandoned. The altitude of the surface is 4,320 feet.

Well No. 63.—Well No. 63, in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 15, T. 52 N., R. 67 W., was drilled in the spring of 1913 by the Mineral Oil Co. to a depth of 510 feet. A little oil (about a gallon) is reported to have been found in the well and flowing water was also obtained, but the casing was drawn and the well abandoned.

Log of well No. 63, SW. $\frac{1}{4}$ sec. 15, T. 52 N., R. 67 W.^a

[Altitude of surface, 4,210 feet.]

Probable formation or member.	Driller's description of the rock.	Content.	Thick- ness.	Depth.
			<i>Feet.</i>	<i>Feet.</i>
Mowry shale member of Graneros shale.	Black shale.....	.....	220	220
Sandstone member of Graneros shale.	Dry sand.....	.....	10	230
Lower shale member of Graneros shale.	Black shale.....	.....	240	470
Dakota sandstone.....	Sand.....	Water..	35	505
(?)	Black shale.....	.....	5	510

^a This log is taken in part from a report by L. W. Trumbull, State geologist of Wyoming, on the Moorcroft oil field (in press).

Well No. 64.—Well No. 64, in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 15, T. 52 N., R. 67 W., was drilled in the spring of 1913 by the Mineral Oil Co. to a depth of 340 feet. A little oil is reported, but the casing was drawn and the well abandoned. The altitude of the surface is 4,195 feet.

Well No. 65.—Well No. 65, in the SE. $\frac{1}{4}$ sec. 16, T. 52 N., R. 67 W., was drilled to a depth of 982 feet in the spring of 1913 by the Mineral Oil Co. A little oil and water is reported, but the casing was drawn and the well abandoned. The altitude of the surface is 4,230 feet.

CHARACTER AND COMPOSITION OF THE OIL.

From the analyses which follow it is evident that there are in the Moorcroft field two distinct oils, differing widely from each other in character. Each of these is a heavy oil, having a specific gravity above 0.9000. The lighter of the two has a specific gravity of 0.9198 and according to David T. Day is a paraffin-base oil. It contains a small amount of water and little or no sulphur. The sample analyzed had apparently by exposure lost gasoline and other of its more volatile constituents. Mr. Day states that "the oil is easily refined and a fresh sample will probably show considerably greater proportions of gasoline and illuminating oil. The sample analyzed is suitable for the manufacture of lubricants." (See analysis of sample No. 1, p. 94). The well from which this oil came (No. 34, Pl. III) is reported to be capable of producing about 5 barrels a day, but at the time of the writer's visit (June, 1913), it was not in operation. The well was fitted with a pump, and any one desiring a small quantity of oil could obtain it by pumping by hand.

Another much heavier oil seeps from the Fuson shale at the Bird Oil Spring (location 19, Pl. III), in the SE. $\frac{1}{4}$ sec. 11, T. 51 N., R. 67 W. An analysis of this oil was not made, but according to Mr. Day it contains 8 per cent of asphalt and is composed entirely of unsaturated hydrocarbons.

Sample No. 2, in the following table of analyses, was obtained from a piece of the asphalt taken from the bank above the Bird Oil Spring. Regarding this sample, Mr. Day says:

This is a rock which is shown by analysis to contain 17½ per cent of oil, fairly soluble in ether. The oil, after extraction, contains 8 per cent of asphalt. It is, however, composed entirely of unsaturated hydrocarbons and does not owe its dark and thick character to surface oxidation but has seeped out in very much the condition in which it is found. The fact that this oil consists of unsaturated hydrocarbons would indicate that the usual proportion of saturated hydrocarbons had been lost by diffusion into some wall rock.

Analyses of oils from the Moorcroft oil field, Wyo.

[Made in the laboratory of the United States Geological Survey, David T. Day in charge.]

Sample No.	Location number on Pl. III.	Depth (feet).	Physical properties.			Distillation.						Asphalt.	Paraffin wax.
			Specific gravity.	Baumé gravity (°).	Color.	Begins to boil.	Gasoline.	Kerosene.	Residuum.				
1.....	35	615	0.9198	22.2	Dark green..	° C. 130	Per cent. 0.5	Per cent. 24.0	Sp. gr. 0.858	Per cent. 76.0	Sp. gr. 0.9400	Per cent. None.	Per cent. 2.5
2.....	19	.....	Thick.	.....	Very dark..	.....	.....	.....	.....	.....	.....	8.0	.....

PRODUCTION AND FUTURE DEVELOPMENT IN THE FIELD.

The production of oil in the Moorcroft oil field is very small, being limited at the time of the writer's visit in June, 1913, to an occasional small quantity for lubrication, pumped by hand from one of the seven wells in the NW. ¼ sec. 34, T. 52 N., R. 67 W. It is reported, however, that each of these seven wells would yield by pumping for a short time about 5 barrels each a day.

The amount of money which has been invested in prospecting and trying to develop the Moorcroft field is estimated at about \$200,000, which is perhaps \$199,000 more than has ever been realized from sales of oil.

The field, according to the development already done, has shown little of value, and as it has been thoroughly prospected it probably will never have any great production. In spite of this fact the writer is informed that in February, 1914, several companies were engaged in drilling wells in the field.

GEOLOGY.

STRUCTURE.

The Moorcroft oil field is on the extreme west edge of the Black Hills uplift. The attitude of the rocks of this field is monoclinial, with a general westward dip, but the amount of dip differs somewhat in different parts of the field. In general it is steepest (about 10°)

near the foot of the high ridge on the east side of the field and lower (from 2° to 7°) at a distance from the ridge. Exception is found to this general monoclinical structure in a rather irregular anticline in the eastern part of the field. In the northwest part of T. 50 N., R. 66 W., this anticline dies out, the rocks becoming nearly flat. A similar condition obtains at the north end of the anticline axis in T. 52 N., R. 67 W. In sec. 12, T. 52 N., R. 67 W., there is a very shallow syncline parallel to and on the eastern side of the anticline.

The two cross sections, A-B and C-D, show the general attitude of the formation along the lines designated by these letters.

STRATIGRAPHY.

SEQUENCE OF THE ROCKS.

The Moorcroft oil field is bounded on the north by the Devils Tower quadrangle, of which the Mesozoic formations, comprising about 4,500 feet of sandstone and shale with local bands and concretions of limestone, have been mapped and described by Darton and O'Harra.¹ The formation boundaries in the northernmost two tiers of sections in T. 52 N., R. 67 W., are taken from their map (see Pl. III), and the following generalized section is also taken in part from their work, differing from their section mainly in the thickness of the formations. For the areal distribution of the formations given in the section see the general map (Pl. III, p. 104).

¹ Darton, N. H., and O'Harra, C. C., U. S. Geol. Survey Geol. Atlas, Devils Tower folio (No. 150), 1907.

Generalized section of rocks in the Moorcroft oil field, Wyo.

System.	Series.	Group.	Formation.	Character.	Thick- ness.	Character of topography and soil.
Cretaceous.)	Upper Cretaceous.	Montana.	Fox Hills sandstone.	Friable sandstone and sandy shale.	<i>Fed.</i>	Rolling hills and rounded ridges; sandy soil with good grass.
			Pierre shale.	Dark shale with calcareous concretions.	2,000	Wide plains with shallow valleys; thin, clayey, and not very fertile soil, supporting fair growth of grass.
			Niobrara shale.	Gray calcareous shale.	100	Shale slopes; limy soil.
		Colorado.	Carlisle shale.	Gray shale with oval concretions and thin sandstones.	500	Rolling hills with thin clay soil, mostly covered with grass.
			Greenhorn formation.	Shale with impure concretionary limestone.	175	Small bare ridges.
	Lower Cretaceous.		Graneros shale.	Black shale with concretions. Hard gray shale containing many fish scales (Mowry shale member). Sandstone, oil bearing. Black shale with small concretions.	1,245	Wide valleys containing extensive alluvial deposits. Shaly ridges, partly wooded. Valleys with clay soil and bedlands.
			Dakota sandstone.	Gray to buff sandstone, mostly very massive; weathers reddish brown.	50+	Plateaus, canyons, and high cliffs with rocky slopes; thin sandy soil.
			Fuson shale.	Shale and sandy shale with local sandstone.	70	Slopes below cliffs of Dakota sandstone.
			Lakota sandstone.	Light-colored coarse massive sandstone.	25-50	Canyons with cliffs; thin sandy soil.
			Morrison shale.	Massive pale greenish-gray to maroon shale with limestone nodules.	125±	Steep slopes below cliffs of Lakota sandstone; poor soil.

JURASSIC OR CRETACEOUS SYSTEM.

MORRISON SHALE.

The Morrison shale outcrops at two localities in the Moorcroft oil field—in the narrow, deep valley of the Belle Fourche in the southwest part of T. 51 N., R. 66 W., and in a gorge occupied by a tributary of Cabin Creek in secs. 11 and 14 of T. 52 N., R. 67 W. At both these places the outcrop consists of shale, prevailinglly bluish gray, but containing also some maroon and purplish tints. The formation is predominantly shale, but contains a bed about 2 feet thick of very fossiliferous impure limestone, which lies near the base of the exposure.

The sections of the Morrison shale exposed in the Moorcroft oil field were not measured, but Darton and O'Harra¹ give a number of sections of the Morrison in the Devils Tower folio. The section nearest the Moorcroft oil field which was measured is near Lytle Creek, about 10 miles northeast of this field, and is as follows:

Section of Morrison shale 4 miles east-southeast of Devils Tower, north of Lytle Creek.

	Feet.
Fire clay, impure, rough, nodular, overlain by Lakota sandstone....	2
Shale, green.....	12
Fire clay, sandy.....	1
Shale, green, locally with purple tinge.....	70
Shale, lime-clay.....	6
Shale, green and drab, fine.....	12
Shale, green, with some lime-clay nodules.....	16
Limestone, slightly argillaceous, lying on Sundance formation.....	6

125

Darton and O'Harra state, regarding the fossils and age of the Morrison shale in the Devils Tower quadrangle, that:

The Morrison shale contains many large bones, and in other areas it has yielded a varied vertebrate fauna, consisting of many genera of dinosaurs, some of which are of huge size, and of primitive forms of small mammals. This fauna, which is often called the *Atlantosaurus* fauna, is thought by some paleontologists to be of early Cretaceous age and by others is assigned to the late Jurassic. The invertebrate fossils are all fresh-water forms which furnish no positive evidence as to age.

CRETACEOUS SYSTEM.

LOWER CRETACEOUS SERIES.

Lakota sandstone.—The Lakota sandstone outcrops about the areas of Morrison shale in secs. 19, 29, and 30, T. 51 N., R. 66 W.; in secs. 11 and 14, T. 52 N., R. 67 W.; and also at a number of other places where erosion has cut through the Dakota and Fuson formations in

¹ Op. cit., pp. 2-3.

the area indicated on the map (Pl. III) as Dakota. The latter areas were considered too numerous and of too small extent to warrant mapping in the short time at the writer's disposal. Wherever noted in the Moorcroft field the Lakota sandstone consists of light-colored coarse-grained massive sandstone which forms cliffs. It is similar to the Dakota sandstone, and without knowing the relative positions one might easily confuse the two. Darton and O'Harra¹ state that the Lakota sandstone "is not so continuously massive, and, although hard in some localities, it is generally softer than the Dakota and forms a less marked feature in the topography."

These authors state further that "the thickness of the Lakota varies considerably and in many places [in the Devils Tower quadrangle] it is difficult to separate it from the overlying Fuson formation. Near the head of Burnt Hollow it is apparently only 25 feet thick, and near the head of Deer Creek and on Sourdough Creek it is 30 feet thick." The thickness of 30 feet agrees closely with the writer's observations in the Moorcroft field and also with the thickness measured by Darton and O'Harra on Cabin Creek a mile or so from the Moorcroft field.

The Lakota was not studied in detail in the Moorcroft field, but a section measured several miles to the northeast on Sourdough Creek is given by Darton and O'Harra as follows:

Section of Lakota sandstone northeast of the Moorcroft oil field on north side of Sourdough Creek.

	Feet.
Sandstone, yellowish gray, massive, overlain by Fuson shale.....	10
Sandstone, purplish gray, soft.....	1
Sandstone, purplish, flaggy, with several bands of iron oxide.....	14
Sandstone, massive.....	1
Sandstone, shaly.....	1
Sandstone, massive, soft, lying on Morrison shale.....	3
	30

No fossils were obtained from the Lakota sandstone in the Moorcroft field, but fossil cycads and petrified wood have been collected from it in various parts of the Black Hills.

Fuson shale.—The Fuson formation consists largely of clay and shale with some thin beds of sandstone. It forms the slope between the Dakota and Lakota sandstones and locally is developed into badlands, especially along the west side of the highest ridge in the eastern part of the field.

Two areas of the Fuson shale are shown on Plate III. Other smaller exposures also occur, but the time at the writer's disposal would not permit of mapping. These small outcrops of the Fuson not shown on the map are included in the area mapped as Dakota.

¹ Op. cit., p. 3.

Darton and O'Harra¹ state that:

Sandstones appear in nearly every exposure of the formation, and in general in this area the Fuson is much more sandy than in other parts of the Black Hills uplift, where it contains much soft shale and fire clay. The thickness varies from 50 to 100 feet, but some of the measurements are indefinite on account of the changeable nature of the various beds.

In the Moorcroft field no detailed sections of the Fuson were measured but from altitudes determined on the base and top of the formation and a measurement of the dip the thickness in sec. 14, T. 52 N., R. 67 W., is calculated to be 70 feet. This exposure contains a rather prominent sandstone bed near the middle of the formation. A detailed section of the Fuson shale north of Cabin Creek near the northeast corner of the Moorcroft oil field is given by Darton and O'Harra as follows:

Section of Fuson shale north of Cabin Creek, near northeast corner of Moorcroft oil field.

	Feet.
Shale, yellowish gray, sandy, darker near top, overlain by Dakota sandstone.....	36'
Sandstone, yellowish, massive.....	3
Shale, yellowish, sandy.....	6
Sandstone, yellowish, massive.....	5
Shale, yellowish gray, darker near the top, lying on Lakota sandstone.	50
	100

In connection with this section Darton and O'Harra state that:

Some of the sandy clays of the Fuson formation contain fossil plants, mostly ferns and conifers, which have been collected extensively in the neighboring Aladdin quadrangle. The species are numerous and their age is Lower Cretaceous.

No fossils were collected from the Fuson shale in the Moorcroft oil field.

The Bird Oil Spring in sec. 2, T. 51 N., R. 67 W., described on pages 89-90, comes to the surface in friable sandstone of this formation.

UPPER CRETACEOUS SERIES.

Dakota sandstone.—The Dakota sandstone, which lies at the base of a thick mass of shale, is the most conspicuous formation of the Cretaceous system in this region. It rises gently toward the east, forming dip slopes which are especially notable on the higher parts of the anticline on the east side of the field.

An exposure in sec. 14, T. 52 N., R. 67 W., shows the following section:

Section of Dakota sandstone in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 14, T. 52 N., R. 67 W.

	Feet.
Sandstone, brown, cross-bedded and massive.....	20
Sandstone, light brown or yellowish gray, rather friable and thin-bedded (indistinctly exposed in upper 10 feet).....	30
	50

¹ Op. cit., p. 3.

In the Moorcroft field the Dakota differs somewhat from the above description. Isolated monument-like forms of weathered material have a distinct gray color with some reddish-brown tints. In at least a part of the area there is some carbonaceous shale in the upper part. At one exposure in sec. 31, T. 51 N., R. 66 W., the shale contains 1 foot 6 inches of bony coal.

No fossils were collected from the Dakota sandstone in the Moorcroft field, but according to Darton and O'Harra it carries in the Black Hills "remains of dicotyledonous plants of late Cretaceous age."

Graneros shale.—The Graneros shale is described by Darton and O'Harra¹ as follows:

The Graneros formation in this quadrangle [the Devils Tower] consists of four distinct members—the lower black shale, a massive sandstone, the Mowry beds, and the upper shale—the total thickness being about 1,250 feet. These divisions are clearly defined lithologically and widely exposed. They are also distinct topographically, the massive sandstone and the overlying Mowry beds rising in ridges of moderate prominence from valleys of the adjoining shales.

The sandstone of this formation is the main oil-bearing bed of the Moorcroft field and probably is also the oil-bearing sandstone in the vicinity of Newcastle.

In the Moorcroft field the Graneros outcrops in a zone about 2 miles wide along the west side of the anticlinal ridge. At both the north and south ends of the ridge the outcrops swing toward the east and as the dip becomes less the zone of outcrop becomes wider.

The lower shale of the Graneros formation occupies a rather narrow zone, generally a valley between the more resistant sandstone of the Dakota below and the oil-bearing sandstone above. As stated by Darton and O'Harra:¹

The rock is a fissile shale of dark-gray or intensely black color. Small deposits of sandstone and sandy shales occur near the bottom, and here and there iron-charged concretions 1 to 2 feet in diameter are scattered through the middle and upper portions, but they show at few places, except in the extensive exposures, and are nowhere abundant. * * * The thickness of the shale varies considerably, but is prevailingly greater in the central and northern portions of the quadrangle. On the southern border it is 120 feet. In Barnard Canyon, due north of Devils Tower, it is 150 feet. On T. L. Creek it is a little more than 200 feet, but the full thickness is not revealed. It can not, however, be much over 200 feet.

In the Moorcroft field the thickness at several points along the outcrop is calculated by the writer to be about 300 feet, but there may be a thickening of the shale in this region due to its being folded between the more resistant Dakota sandstone below and the oil-bearing sandstone above.

The sandstone overlying the black shale outcrops in a narrow ridge parallel to the exposure of the shale. It is immediately over-

¹ Op. cit., p. 4.

lain by the Mowry shale member and is composed of beds of sandstone, shale, and clay. A section in the SE. $\frac{1}{4}$ sec. 22, T. 52 N., R. 67 W., shows a thickness of 45 feet as follows:

Section of sandstone part of the Graneros shale in the SE. $\frac{1}{4}$ sec. 22, T. 52 N., R. 67 W.

	Ft. in.	
Shale, drab, friable (overlain by Mowry shale member).....	2	0
Sandstone, rusty brown, concretionary, containing fossil invertebrates.....		8
Shale, bluish gray, soft, sandy.....	2	0
Sandstone, grayish brown, friable, shaly; a few fossil invertebrates and plant stems.....	4	0
Shale, black, very carbonaceous.....		6
Clay, light brown, soft.....	3	0
Shale, black, carbonaceous.....		5
Shale, light bluish gray, sandy.....		10
Sandstone, grayish brown, hard, containing plant stems and a deciduous leaf.....	1	6
Shale, dark, sandy.....	6	0
Sandstone, gray on weathered surface, brown on fresh surface....	5	0
Sandstone, gray, friable, soft, shaly.....	4	6
Shale, dark, very carbonaceous.....	2	0
Clay, light bluish gray, soft.....	1	4
Shale, bluish gray.....	7	0
Shale, dark, carbonaceous, sandy.....	2	0
Sandstone, gray on weathered surface and brown on fresh surface, with strong odor of oil; friable and containing plant stems.....	2	10
	45	7

The sandstone of the Graneros shale probably is not as well developed in the Moorcroft oil field as farther north in the Devils Tower quadrangle. It is described by Darton and O'Harra¹ in the Devils Tower folio as follows:

The rock is a massive sandstone of medium to coarse grain and in a few places it becomes a conglomerate. The conglomeratic character is well developed in the two areas west and northwest of the Missouri Buttes. The rock in the outcrops nearest the buttes consists largely of pebbles about the size of a pea, while in the larger area 2 or 3 miles away many of the pebbles are 1 inch in diameter and there are some reaching 2, 3, or even 4 inches. The thickness of the sandstone varies from 8 feet, as the approximately general amount south of Poison Creek, to 50 feet in the area south and west of Elkhorn Creek.

Of the areas mentioned by Darton and O'Harra the nearest to the section given above from the Moorcroft field is about 12 miles distant. In the Moorcroft field the whole of the sandstone is not well exposed except in very few places, but certain beds may be seen almost anywhere along the line of outcrop, which is shown on the map (Pl. III).

The Mowry shale member of the Graneros shale outcrops in a zone about one-half mile wide immediately west of the outcrop of the

¹ Op. cit., p. 4.

sandstone. The top of the shale is not clearly defined in the Moorcroft field. Nearly everywhere it is located on grassy slopes and is therefore concealed. In mapping this boundary the line was in most places drawn at the west border of the strip of pine timber, which in this region is largely limited in its growth to the soil of the Mowry shale. This line may be stratigraphically a little too high to conform with the calculated thickness (300 feet) of the Mowry. This mapping in fact makes it nearly twice as thick as in the Devils Tower quadrangle where it was measured by Darton and O'Harra,¹ although the total thickness of the Mowry and that of the upper shale member of the Graneros as mapped in the Moorcroft field is about the same as that of these two members in the Devils Tower quadrangle.

Darton and O'Harra describe the Mowry as follows:

The material is a compact shale of dark color, containing large numbers of detached fish scales. These scales are found in all portions of the member, but vary in abundance. In places they are closely packed together, while in some beds they are somewhat widely scattered. In general they are sprinkled singly over the shale surfaces, in the proportion of one to four scales in 6 square inches. They range mostly from one-half to three-fourths of an inch in diameter.

In the hand specimen of fresh rock the shale differs little in general appearance from that of the lower Graneros except in fissility, the lower beds being thin and papery, while the Mowry scale shales are thicker or more slabby and considerably harder. Owing to the fact that the Mowry beds are much harder than the adjoining shales, they give rise to hills and ridges of moderate prominence. They afford a fairly firm hold for tree roots, and as a result the Mowry hills are generally well covered with pines and scrub oaks. The shales are dark gray or decidedly black when fresh, but, unlike the other Graneros shales, weather through drab to a light gray, and this light color, together with the wooded hills and ridges, causes the Mowry outcrop to be very conspicuous. The contact of the Mowry beds with the underlying sandstone is in most places distinct, but the contact with the overlying upper Graneros shale is as a rule concealed by the mingled shales of the two members.

In the Moorcroft field the contact of the Mowry shale with the underlying sandstone is less definite than the description in the Devils Tower folio would indicate it to be in that region. In most places there is at least a low valley between the pine-clad ridge of the Mowry on the west and the sandstone ridge to the east. It appears, therefore, that the lower part of the Mowry is less resistant than the upper part.

The soft shale constituting the upper part of the Graneros formation occupies a more or less distinct valley about three-fourths of a mile wide, lying immediately west of and parallel with the outcrop of the Mowry shale member. This upper shale in general is similar to the lowest shale of the Graneros but contains more calcareous concretions, especially in the upper 150 feet. They are in fact so numerous that locally they form ridges. The upper shale also con-

¹ Op. cit., p. 4.

tains some very hard iron carbonate concretions, ranging in diameter from 6 to 10 inches.

Calculations made from the distances between the boundaries as mapped in the field indicate that the upper shale is about 600 feet thick, but Darton and O'Harra¹ state that west of Little Missouri River, about 20 miles north of the Moorcroft field, it is approximately 850 feet thick.

Greenhorn formation.—The Greenhorn formation outcrops in a narrow zone less than one-fourth of a mile wide and forms a rather prominent ridge west of the outcrop of the upper part of the Graneros shale. It is described as follows by Darton and O'Harra:¹

It consists of alternating beds of lime-clay concretions and black shales, the shales being almost identical in general appearance with the Carlile and upper Graneros shales and the concretions not differing greatly from those of the Carlile. The concretions are of sufficient importance, however, to give a perceptible topographic effect, and with careful observations, in the absence of good exposures, the general position of these beds may be traced over the gently undulating surface. The concretions vary from a few inches to several feet in diameter, the usual size being 1 to 4 feet. They have a bluish-gray color and are spherical or ellipsoidal in shape. Here and there they show a well-developed septarian character, and a fair proportion contain fossils, chiefly *Inoceramus labiatus*, a fossil which is characteristic of this formation. The thickness of the formation varies between 60 and 80 feet, but its stratigraphic limits are somewhat indistinct.

The Greenhorn formation as mapped in the Moorcroft field is about 175 feet thick, but the stratigraphic limits are so indefinite that some of this thickness, as given in the table, may include a part of the Graneros shale below or some of the Carlile shale above.

Carlile shale.—The outcrop zone of the Carlile shale is parallel with that of the other formations of the Moorcroft field and occupies a strip of country a little over a half mile in width, as indicated on the map (Pl. III). The greater part of the outcrop consists of gentle grass-covered slopes. Darton and O'Harra² describe the Carlile shale in the Devils Tower quadrangle as—

made up of three fairly distinct divisions. The upper division is about 300 feet thick and is nearly all shale; few concretions are present and these occur at indefinite horizons. The middle division is 125 feet thick and consists of concretions and shale, the concretions being of considerable size and in sufficient number to leave an impress on the topography in favorable localities. The lower division is 200 feet thick and, like the upper division, is chiefly shale, only a few concretions being observed. The middle series much resembles the Greenhorn formation, but lacks the distinctive *Inoceramus*.

Niobrara shale.—The outcrop zone of the Niobrara shale was mapped as shown on Plate III on the evidence of material brought to the surface in drilling a well (No. 41) in sec. 33, T. 52 N., R. 67 W., and by extending the boundaries mapped by Darton and O'Harra in

¹ Op. cit., p. 4.

² Idem, pp. 4 and 5.

the Devils Tower quadrangle (the north two tiers of sections of T. 52 N., R. 67 W., are a part of the Devils Tower quadrangle).

The material on the dump pile of well No. 41 in sec. 33, T. 52 N., R. 67 W., consists of bluish-gray, very calcareous shale. No outcrop of the shale was seen in the Moorcroft field, as it is concealed by grassy slopes, but a thickness of about 100 feet is probably present, as in the Devils Tower quadrangle to the north. Darton and O'Harra¹ describe the lithologic character of the Niobrara shale as follows:

The lithologic character of the Niobrara in this quadrangle is identical with that which is so uniformly peculiar to it throughout the Black Hills region—that is, it consists of soft, light-gray, slabby shales, weathering to creamy yellow and chalky gray, finely dotted with white specks and carrying thin, irregular aggregates of *Ostrea congesta*.

Pierre shale.—The outcrop zone of the Pierre shale is about 2 miles wide and is parallel to the outcrop of the other formations of the Moorcroft field. Its strike is nearly north and south (Pl. III). The Pierre shale in this field as elsewhere consists chiefly of dark soft shale, weathering into broad gentle slopes and low rounded hills. In the SE. $\frac{1}{4}$ sec. 20, T. 52 N., R. 67 W., there is a change in the character of the thinly grassed sagebrush soil of the Pierre shale area from a surface covered with chips of iron oxide on the east to one barren of such iron oxide chips on the west.

The thickness of the Pierre shale in the Moorcroft oil field is calculated from field observations to be about 2,000 feet. It rests on the Niobrara shale below and is overlain by the Fox Hills sandstone.

Fox Hills sandstone.—The outcrop of the Fox Hills sandstone occupies a zone of grass-covered hills with gentle slopes lying immediately west of the Pierre shale. It outcrops in a belt about three-fourths of a mile wide and, like the outcrops of the other formations, extends in a north-south direction (Pl. III). It occupies only a small area in the region mapped. The sandstone is not well exposed, but there is no reason to believe that it differs materially from that at a locality in T. 48 N., R. 66 W., several miles to the southeast, where in 1911 the writer measured the following section:

Section of Fox Hills sandstone in sec. 20, T. 48 N., R. 66 W.

	Feet.
Sandstone, light brown.....	38
Shale, light and dark gray, sandy.....	83
Sandstone, light brown.....	27
Shales, tan and blue gray, sandy (transitional shale at base of Fox Hills).....	38
	186

¹ Op. cit., p. 5.

WYOMING.

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POSSIBILITIES OF OIL IN THE BIG MUDDY DOME, CONVERSE AND NATRONA COUNTIES, WYOMING.

By V. H. BARNETT.

INTRODUCTION.

Since the successful development of the Salt Creek oil field on a pronounced dome-shaped structure 50 miles north of Casper, prospectors have been busy searching similar structures in different parts of the State, and though the search has in few places been rewarded by the discovery of oil in commercial quantity, it still continues and probably will not cease until every such structure has been tested by the drill. Although this method of prospecting involves the expenditure of a large amount of money, it is the only one by which the question of the presence or the absence of oil can be determined. The United States Geological Survey desires to aid the prospectors, and with that object in view is constantly searching for domes or other structures favorable for the accumulation of oil, for by pointing out these more favorable locations a large amount of entirely useless drilling may be prevented. Although the Survey does not guarantee that oil will be found in any of these domes, its position is that such domes are the most promising localities; and if the drill proves that they do not contain oil, it is useless to search in other places. The object of the present paper is to describe such a dome or anticline in the vicinity of Big Muddy Creek on the south side of North Platte River.

LOCATION AND DEVELOPMENT OF THE FIELD.

The area described in this paper extends along both sides of North Platte River from the vicinity of Casper to a point beyond Glenrock (fig. 2, p. 84). It comprises an area of about 325 square miles, about half of which lies in Converse County and the other half in Natrona County. (See Pl. IV, p. 116.)

In this area, as in many other undeveloped oil fields, the first drilling has been done near surface indications and some distance from the locality most favorable, so far as structure is concerned, for an oil well. In 1912 the Wyoming Oil, Gas & Power Co. drilled two

shallow wells in T. 33 N., R. 74 W., within a mile or so of an oil seep.¹ It is not surprising that oil in commercial quantities was not obtained in either of these wells in view of the fact that they were drilled into a monocline, where the dip of the rocks is uniform. Oil seeps are reported also near the southwest corner of the area shown on Plate IV and some drilling has been done near Casper, but none of the wells have been producers. The most favorable place for oil in this area, and in the judgment of the writer the most favorable place within 50 miles of Douglas, is in the flat south of the Northwestern Railway between Glenrock and Big Muddy Creek, near the north-central portion of the area. In this vicinity the structure is favorable, and oil, if present at all, is probably about 2,500 feet below the surface.

ACKNOWLEDGMENTS.

In presenting this report the writer wishes to express his thanks for courtesies extended during the progress of the field work by the people of Glenrock and by every ranchman with whom he came in contact. The writer is indebted to the members of his party, Messrs. J. B. Reeside, jr., Y. T. Wang, Frank Elliott, and Bernard Jackson, for assistance in the examination of the area.

PURPOSE AND METHOD OF THE INVESTIGATION.

The primary object of the investigation of this field was to ascertain the mineral resources, especially oil and coal, for the purpose of classifying the land by legal subdivisions into mineral land and non-mineral land. A secondary object and one closely connected with the first was to determine, as far as possible, the geologic structure, the various formations involved, and the conditions favorable for the accumulation of oil or gas.

The field was mapped on a scale of 2 inches to the mile by means of a plane table and telescopic alidade, the township being the unit represented by each field sheet. A complete system of triangulation² was established covering the field, and the stations of this system served the purpose of both horizontal and vertical control and formed the means for tying the different plane-table sheets together. In beginning the primary control or triangulation a base line 12,800 feet in length was measured with a steel tape along a straight stretch of the railroad, extending from the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 23, T. 33 N., R. 72 W., to the SW. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 31, T. 33 N., R. 71 W. When the field work had advanced to the Big Muddy locality a second base line was measured as a means of checking locations. This second base line extended 14,340 feet along the straight stretch of railroad track

¹ These wells are described in U. S. Geol. Survey Bull. 541, p. 74, 1914.

² The triangulation was done on a larger sheet, the Johnson 24 by 24 inch plane table being used.

from the SE. $\frac{1}{4}$ sec. 8 to the NE. $\frac{1}{4}$ sec. 2, T. 33 N., R. 76 W., and is consequently near the center of the area here discussed.

All the section corners that were found in the course of the field work were located on the map with respect to triangulation stations, and their locations are therefore correct in so far as the scale of the map and the methods of location would permit. No attempt was made to find all the section corners, but in each township a considerable number were found. Attitudes were determined throughout a large part of the area by means of vertical angles. Stadia traverses were employed in conjunction with triangulation for mapping formation boundaries and similar purposes. The net shown on the map is based on section corners located in the field and supplemented by the General Land Office plats.

TOPOGRAPHY.

The area of the Big Muddy dome may be described in a general way as a rolling prairie bordered on the south by a low range of mountains. In detail there are many variations from this type in the form of numerous ridges, table-like buttes, gentle slopes, and broad valleys. Several small streams, which emerge from the mountains through deep canyons, cross the area in flat-bottomed valleys and empty into North Platte River. The part of the field most favorable for oil accumulation lies in the broad shale valley of the North Platte, mainly in T. 33 N., R. 76 W. A rather prominent ridge borders the southeast side of this valley, separating it from Deer Creek valley.

The elevation in the valley of North Platte River, the lowest part of the field, is about 5,000 feet above sea level, but the land rises toward the south until at the foot of the mountains it is about 6,000 feet above sea level. Thence to the summit of Casper Mountain, a horizontal distance of about 2 miles, the surface rises about 1,500 feet, or to 7,500 feet above sea level.

Farming is carried on extensively in favorable localities, where alfalfa, timothy, and small grain are profitably raised by irrigation. The part of the area not under cultivation yields a good growth of grass, which supplies perennial range for stock.

The rainfall is not sufficient to support a growth of timber, except scattered cottonwood and boxelder trees along the streams and a few scrubby pine and cedar trees on some of the rocky hills. However, marketable pine timber grows in the mountains to the south, especially on the high slopes of Casper Mountain.

Fuel for domestic use consists, for the most part, of pine and cedar wood from the mountains and coal from Glenrock or Big Muddy mines.

The several streams which rise in the mountains and flow across the field to North Platte River yield a good supply of fresh water for

domestic use. All these streams are fed by springs in the mountains and so maintain a fairly constant flow of water, which is utilized for irrigation in the broad bottom and on some of the bench lands. A much greater area might be irrigated if large storage reservoirs were constructed.

GEOLOGY.

STRATIGRAPHY.

SEQUENCE OF THE ROCKS.

The rocks in the vicinity of the Big Muddy dome include about 10,000 feet of Paleozoic and Mesozoic formations, ranging in age from Carboniferous to late Cretaceous, and also some beds of Tertiary and Quaternary age. The Paleozoic rocks are not described in this paper.

The following generalized section shows the character and thickness of the Mesozoic and later formations and their relations to each other:

Generalized section of formations involved in the Big Muddy dome, Wyo.

System.	Series.	Group.	Formation and member.	Character.	Type of topography and soil.	Thickness.
Quaternary.				Alluvium, gravel, and sand.	Sand dunes, gravel-topped hills, and valley flats.	<i>Feet.</i> 25+
Tertiary.	Oligocene.		Unconformity White River formation.	Clay, conglomerate, and sandstone.	Flat-topped hills and gentle slopes; thin soil.	1,000
Tertiary(?).	Eocene (?).		Unconformity Lance formation.	Friable sandstone and shale, with local beds of coal.	Rolling hills and broad gentle slopes; thin sandy soil and alkali flats.	200+
			Fox Hills formation, base uncertain.	Friable sandstone and shale with local coal beds near top.	Ridges of sandstone and valleys in shale; sandy soil.	880
				Sandy shale.	Valleys; thin clay soil.	400
		Montana.	Teapot sandstone member.	Gray and buff sandstone and carbonaceous shale.	Low ridges, barren rock slopes, and pine-clad hills.	160
				Sandy shale.	Valleys; thin clay soil.	320
			Parkman sandstone member.	Friable sandstone and beds of shale and coal.	Ridges of some prominence and broad grassy slopes.	330
				Dark shale.	Broad valleys; thin soil.	2,000
	Upper Cretaceous.		Niobrara shale.	Gray to buff calcareous shale.	Low rounded ridges and brown slopes.	100-650
				Dark shale.	Narrow valleys; thin soil.	200
		Colorado.	Wall Creek sandstone member.	Gray and buff sandstone and beds of shale.	Ledges and hogback ridges covered with small pines.	100-200
			Benton shale.	Dark shale including Mowry shale member.	Broad valley with low rounded pine-clad ridge of Mowry shale. Thin soil.	1,200
	Lower Cretaceous.		"Cloverly" formation.	Buff sandstone and shale with conglomerate in lower part.	Ledges, hogback ridges, and barren slopes of rock; thin sandy soil.	140
Jurassic or Cretaceous.			Morrison formation.	Green, buff gray, and maroon shale and thin beds of sandstone.		
Jurassic.	Upper Jurassic.		Sundance formation.	Greenish-gray limestone and sandstone.	Gentle slopes below ridges of "Cloverly" rocks.	700

JURASSIC SYSTEM.

SUNDANCE FORMATION.¹

The Sundance formation outcrops locally in a narrow belt along the north and east sides of Casper Mountain and along the north slope of the mountain range immediately south of the field. It is lithologically similar to the overlying Morrison formation, each consisting predominantly of shale, in which there are intercalated beds of sandstone and limestone. The Sundance is of marine origin and contains more limestone than the overlying Morrison. No estimate of the thickness of the Sundance was obtained in this field, but the total thickness of this formation and the Morrison in sec. 33, T. 32 N., R. 78 W., is about 700 feet.

JURASSIC OR CRETACEOUS SYSTEM.

MORRISON FORMATION.¹

The Morrison formation is poorly exposed in this field, being almost wholly concealed by talus from the overlying sandstone of the "Cloverly" formation. With the Sundance and "Cloverly" formations it occupies a narrow belt along the southern part of the field as shown on the map (Pl. IV, p. 116).

The Morrison formation consists of a bluish-gray and maroon-colored shale interbedded with thin bands of limestone and sandstone. No estimate of the thickness of the Morrison was obtained, but from a measurement in T. 31 N., R. 71 W., several miles to the east, it is estimated to be about 200 feet.

CRETACEOUS SYSTEM.

"CLOVERLY" FORMATION.¹

The "Cloverly" formation is exposed in a narrow belt along the north and east slopes of Casper Mountain and near the foot of the mountain range along the south side of this field. A section of the formation at the east end of Casper Mountain reveals about 140 feet of sandstone, conglomerate, and shale. The section in detail is as follows:

Section of the "Cloverly" formation in SE. $\frac{1}{4}$ sec. 11, T. 32 N., R. 76 W.

	Feet.
Sandstone, brown and gray (gray on fresh surface).....	20
Shale and sandstone (largely covered).....	60
Sandstone, gray, fine grained	10
Concealed, probably shale.....	5
Sandstone, brown to gray, fine grained, sharp grit (gray on fresh surface).....	25
Conglomerate, brown and gray, pebbles generally one-sixteenth to one-half inch in diameter (about 100 feet north this conglomerate is 27 feet thick)	17

¹ Not shown on the map.

Only the more resistant members of the "Cloverly" are well exposed, the more shaly portion being in most places concealed. In this field the dip of the "Cloverly" formation ranges from 12° to vertical, or the formation is slightly overturned, and its outcrop is in most places marked by a hogback ridge. The lower part of the formation is locally conglomeratic. Loose blocks of the conglomerate cover slopes in places several hundred yards from the outcrop. The conglomerate ranges in thickness from a few inches up to about 30 feet.

In the vicinity of the Black Hills the formations between the Benton above and the Morrison below consist of Dakota sandstone, Fuson shale, and Lakota sandstone, the Dakota sandstone being of Upper Cretaceous and the others of Lower Cretaceous age. Westward from the Black Hills the Dakota is generally absent, and in the Bighorn Basin the beds occupying this interval are all supposedly of Lower Cretaceous age and have been named the "Cloverly" formation, but as there is some doubt about the validity of the term, it has generally been inclosed in quotation marks. In the vicinity of Casper and Douglas the Dakota has not been recognized and hence the term "Cloverly" is used in this report.

BENTON SHALE.

The Benton shale consists of about 1,600 feet of dark and light colored shale with a thick sandstone member near the top. It lies directly upon the "Cloverly" formation and is followed above by the hard and chalky Niobrara shale. The Benton shale comprises a lower 220 feet of dark soft shale overlain by about 175 feet of dark-bluish hard shale, the Mowry shale member, which weathers light bluish gray to yellowish and produces low ridges. Above the Mowry shale is about 870 feet of dark soft shale which is overlain by 100 to 250 feet of gray to yellowish brown sandstone and shale, locally containing abundant fossils. Above the sandstone and below the Niobrara shale there is about 300 feet of dark shale similar to the dark shale in the lower part of the formations.

Section of the Benton shale in sec. 29, T. 33 N., R. 74 W.

	Feet.
Shale, dark.....	300
Sandstone, ridge forming, fossiliferous Wall Creek sandstone member.....	100
Shale.....	867
Shale, dark, weathering light bluish gray; yellowish gray in upper half, and locally forming pine-clad ridges (Mowry shale member).	175
Clay (bentonite?), gray and yellow mottled, interbedded in darker clay. (One bed of the light clay is 8 inches thick).....	3
Shale, dark.....	215
	1,660

The fossiliferous sandstone of the Benton shale in the foregoing section appears to correspond with the Wall Creek sandstone member of the Salt Creek field, as described by Wegemann,¹ and for this reason the term Wall Creek is here tentatively applied.

The Wall Creek sandstone member was measured at two localities farther west and at each was found to be over 100 feet thick. These sections are as follows:

Sections of the Wall Creek sandstone member.

In sec. 5, T. 22 N., R. 78 W.

	Feet.
Sandstone, brown, thin-bedded, friable in lower half.....	75
Sandstone, yellowish gray, massive, with large brown calcareous concretions, about 6 feet in diameter.....	125
	200

East bluff of Big Muddy Creek in T. 22 N., R. 78 W.

Sandstone, dark grayish, coarse grained, becoming rather massive above and firm. Develops hogback ridges where dip is steep..	35+
Sandstone and shale, in alternating bands, the shale in bands not over 1½ inches but the sandstone bands as much as 4 inches thick.	
Upper half, bedded sandstone. (Sandstone is dark gray; shale is dark with carbonaceous material).....	32
Shale, dark, laminated	16
Sandstone, gray, greenish tinged, friable, thin bedded.....	9
Sandstone and dark shale in alternating layers from half an inch to 3 inches thick, thickest bands near the top.....	27
Shale, dark.	
	119+

In T. 32 N., R. 78 W., east of Casper Mountain, there is a sandstone bed in the Benton shale about 320 feet below the Wall Creek sandstone. This sandstone is 15 feet thick, hard in the upper half but massive and friable below. The upper part of this sandstone is ripple marked and contains the marine fossil plant *Halymenites major* Lesquereux.

NIORRARA SHALE.

The Benton shale is overlain by 100 to 650 feet of chalky shale, which contains a few marine fossils of the species *Ostrea congesta* (Conrad) and some fragments of an *Inoceramus* characteristic of the Niobrara shale. The outcrop of this shale is exposed in a narrow belt along the south side of the field and is shown on the map (Pl. IV). The exposures of the shale are not continuous throughout this belt, but it appears at a sufficient number of places to justify the mapping. In T. 32 N., R. 77 W., there is 650 feet of shale exposed, the lower part of which is dark bluish gray and the upper part yellowish in color. *Ostrea congesta* was obtained from the dark shale, but only

¹ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 37-53, 1911.

fish scales from the yellow upper part. The shale throughout is calcareous and is characterized by small specks of white chalk. The yellow shale portion is firmer than that below and contains some concretions of hard compact limestone about 10 inches in diameter.

PIERRE FORMATION.

The Niobrara shale is overlain by about 3,210 feet of shale and sandstone, constituting the Pierre formation, which in this field is composed of five members. The lower member is a dark soft shale 2,000 feet thick, containing some calcareous concretions bearing marine fossils. The next member is about 330 feet thick and composed of sandstone and shale with thin coal beds. This member appears to correspond in stratigraphic position to the Parkman sandstone member as described by Wegemann.¹ In the description of the Pierre formation in the Douglas oil field the writer² compared the section with that of the Salt Creek field but stated that "Further detailed work may prove also that the 150-foot sandstone, here referred to the Parkman, is a much higher sandstone and the 300 ± feet of sandstone, referred to the Shannon sandstone lentil, is the Parkman member, the Shannon sandstone lentil being absent." In the Big Muddy dome the Shannon sandstone lentil does not appear.

Above the Parkman sandstone there is another sandy shale 320 feet thick, yielding marine Montana fossils. Above this shale there is another sandstone about 160 feet thick which contains carbonaceous shale and thin coal beds. This sandstone seems to agree in character and stratigraphic position with the sandstone described by Wegemann³ as forming the Little Pine Ridge east of the Salt Creek oil field. At the time Wegemann's report was published the geographic extent and the value of this sandstone as a key were not known, but the work of Mr. Hares west of Casper and of the writer east of that place has shown that this sandstone is probably the most easily identified member of the Pierre formation. On this account it seems desirable to map it and give it a name. Wegemann describes this member as forming Little Pine Ridge, a name given by him to an escarpment of sandstone next east of that formed by the Parkman sandstone member, but he did not apply the name to the bed. As the name Little Pine Ridge is cumbersome and as it is not in current use in the county, it is thought best to select another. Accordingly the name Teapot sandstone member is given to this sandstone from the "Teapot Rock," a well-known topographic feature carved from this sandstone about half a mile east of the Casper-Salt Creek road.

¹ Wegemann, C. H., The Salt Creek oil field, Natrona County, Wyo.: U. S. Geol. Survey Bull. 452, pp. 46-48, 1911.

² The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, p. 64, 1914.

³ Wegemann, C. H., loc. cit.

The Teapot sandstone member consists of gray and buff sandstone, including some carbonaceous shale, which has a thickness of 50 feet in the type locality and 160 feet in the Big Muddy dome. Overlying the Teapot sandstone there is about 400 feet of dark soft shale with calcareous concretionary masses containing marine Montana fossils.

FOX HILLS FORMATION.

Overlying the 400 feet of dark soft shale forming the upper member of the Pierre formation there is about 860 feet of friable sandstone, sandy shale, and soft dark shale, some part, or all of which, represents the Fox Hills sandstone. Its section is as follows:

Generalized section of the Fox Hills formation near Glenrock.

	Feet.
Sandstone, gray in upper half, buff below.....	100
Shale and shaly sandstone and coal beds.....	120
Sandstone, gray and buff.....	70
Shale.....	320
Sandstone, friable, and sandy shale.....	250
	860

TERTIARY (?) SYSTEM.

LANCE FORMATION.

Rocks of the Lance formation outcrop in the eastern part of this field mostly north of the river, but there is also a small area south of the river in T. 33 N., Rs. 74 and 75 W. The Lance formation, by a recent decision of the United States Geological Survey, has been provisionally classified as of Tertiary (?) age. It consists of friable sandstone, sandy and carbonaceous shales, and coal beds. It is not within the scope of this paper to describe the Lance formation in detail.

TERTIARY SYSTEM.

WHITE RIVER FORMATION.

A small portion of the southeast corner of this field, as shown on the map (Pl. IV), is covered with rocks belonging to the White River formation. This formation rests unconformably on older rocks and is composed largely of clay, though beds of fine sand, limestone, and conglomerate occur at different places in the formation. The total thickness in the area shown on the map is probably not over 200 feet, but farther east, in the Douglas oil field,¹ there is 580 feet exposed, and it is there believed by the author to have a total thickness of about 1,000 feet.

¹ Barnett, V. H., The Douglas oil and gas field, Converse County, Wyo.: U. S. Geol. Survey Bull. 541, p. 66, 1914.

QUATERNARY SYSTEM.

Alluvium along the streams, some local beds of unconsolidated gravel, and loose sand and sand dunes constitute the only beds of Quaternary age in the vicinity of the Big Muddy dome. North of the river the older rocks are largely concealed by the covering of sand and sand dunes, as shown on the map (Pl. IV). There are some terraces and hills capped with gravel, but only a few of these are mapped.

IGNEOUS ROCKS.

Red granite, cut by basic dikes of different kinds, underlies the Paleozoic rocks in the southern part of the Big Muddy field and forms the core of the mountains. Only a small area of the granite is indicated on the map. There are doubtless other exposures in the deep canyons in the southern part of the field.

STRUCTURE.

The Big Muddy dome is a slight arch of the strata extending over an area of about 72 square miles. It is elongated in a southwest-northeast direction, being about 8 miles across in this direction, but only about 3 miles from north to south.

The general shape of the dome is indicated by the outcrop of the formations as shown on Plate IV. Unfortunately in this area the indurated rocks are badly concealed by alluvium along the river and its principal tributaries by sand dunes and gravel-covered terraces, and by the White River formation, which consists of a heterogeneous mass of unconsolidated material that was laid down in a broad lake that once occupied this valley as well as a large area to the east. On account of this cover of soft material the outcrops of the underlying formations are difficult to follow on the map, but the broken lines indicate the probable location of the boundary lines beneath the surface cover.

Thus it will be seen that the anticline extends northeastward from the upward fold in the older rocks in sec. 12, T. 32 N., R. 78 W. The axis of the fold descends gradually from that place to the southeast corner of T. 33 N., R. 77 W. Here the axis either dies out or turns to the north and the fold develops into an elongated dome, the axis of which extends through secs. 7, 8, 9, 3, 2, and 1, T. 33 N., R. 76 W. The magnitude of this dome is such as to bring to the surface that part of the Pierre formation which lies below the Parkman sandstone member. The outline of the dome is shown by the outcrop of the Teapot sandstone member, which dips steeply northward and crosses the southern part of T. 33 N., R. 75 W. This outcrop can be followed southwestward to sec. 31, T. 33 N., R. 76 W.,

where it turns sharply back under cover and is next seen in sec. 12 of the same township. Here it passes around the point of the anticline and then it extends westward along North Platte River, though concealed by alluvium, to sec. 5. West of this place the Teapot sandstone member makes a big swing across the river, indicating the presence of a local fold, and then it can be traced to the southwest, crossing Dry Muddy Creek in secs. 14 and 15, T. 33 N., R. 78 W. From this place it trends northwestward across the river and is last seen in sec. 31, T. 34 N., R. 78 W.

From the axis of the dome in T. 33 N., R. 76 W., the rocks dip in all directions, but toward the southwest the dip is very light, ranging from 1° to 3° . In other directions the dip may be easily read with the clinometer. On the north edge of the dome the rocks dip from 10° to 38° , on the east and southeast from 2° to 11° , and on the west from 1° to 17° away from the central portion. Most of these dips were obtained by clinometer readings, but some were determined by the three-point method, that is, three stadia locations with relative elevations were obtained on a coal bed or some other mappable stratum, and from these data the direction and amount of dip were calculated. The outline of the dome on the north and northwest is rather indefinite on account of the mantle of wind-blown sand.

Near the south side of the Big Muddy field there is a syncline whose axis extends in a rather sinuous course for a distance of about 18 miles (see Pl. IV) from a point near the east end of Big Muddy Mountain in a general northeasterly direction to sec. 31, T. 33 N., R. 76 W., where it bends toward the east, crossing Deer Creek, then bends back toward the northeast again, and finally dies out near the center of T. 33 N., R. 75 W. This syncline is here designated the Deer Creek syncline, because it is best developed in the vicinity of Deer Creek. The dips of the rocks in the eastern half of the syncline on the north side of the axis are from 5° to 7° S., but on the south side of the axis the dips are from 5° to vertical, or the rocks are slightly overturned toward the north. In the western half of the axis the syncline is rather obscure.

There are several large faults in the edge of the mountains along the south side of this field. As stated by Darton,¹ there is a big fault along the north face of Casper Mountain. Other more or less extensive faults also occur in this part of the field, but they are too far from the Big Muddy dome to have any direct bearing on the presence or absence of oil and for this reason they are given no further consideration.

There is, however, a small fault in sec. 1, T. 33 N., R. 76 W., which strikes directly toward the north edge of the Big Muddy dome. The evidence at hand is not sufficient to prove whether or not this fault

¹ Darton, N. H., Preliminary report on the geology and underground water resources of the central Great Plains: U. S. Geol. Survey Prof. Paper 32, pp. 53-55, 1905.



QUATERNARY

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extends beyond the limits indicated on the map (Pl. IV), but it appears to be of little importance. A maximum dip of 46° was measured near the Lockett mine, which is in the line of strike of the fault.

PROBABILITIES OF OIL OR GAS.

In the Salt Creek oil field the Wall Creek sandstone is the chief oil sand, and contains a better grade of oil than any of the other sands of that field. This sandstone doubtless underlies the Big Muddy dome, as its outcrop was traversed along the entire south border of the field, as shown on the map (Pl. IV). It should be reached by drilling near the crest of the dome on the broad shale flat between Glenrock and Big Muddy at a depth of about 2,500 feet, but whether it contains oil or whether it is "dry" can be learned only by the use of the drill. The presence of oil in the dome will, of course, primarily depend upon whether or not the rocks in this field contain oil; if they do, it will probably be found in this dome, but its position in the dome will depend upon the quantity of water carried by the Wall Creek sandstone. If it is saturated to such an extent that the water extends upward above the crest of the dome, then the oil should be found in the crest, as it has been found at Salt Creek, but if the upper limit of saturation does not reach to the crest, then the oil, if it is present, will be found immediately above the upper limit of the water.

It must be clearly understood that the United States Geological Survey has no means of knowing whether oil is present in this dome or not, but it does maintain that if oil is contained in these rocks the chances are decidedly in favor of its having accumulated at some place in the dome. If a test at the highest point should show only water, then it is probably useless to test further, but if a test in the top should reveal dry rock or gas, then it might be possible to find oil lower down in the flank of the fold.



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581—D

GEOLOGY AND OIL PROSPECTS
IN
WALTHAM, PRIEST, BITTERWATER, AND
PEACHTREE VALLEYS, CALIFORNIA

WITH NOTES ON COAL

BY

ROBERT W. PACK AND WALTER A. ENGLISH

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—D



WASHINGTON
GOVERNMENT PRINTING OFFICE

1914

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GEOLOGY AND OIL PROSPECTS IN WALTHAM, PRIEST, BITTERWATER, AND PEACHTREE VALLEYS, CALIFORNIA.

By ROBERT W. PACK and WALTER A. ENGLISH.

INTRODUCTION.

In the investigation of the California oil fields made by the United States Geological Survey during the last 14 years the areas outside of the productive fields have received special attention, with the view to aiding the prospector by determining, so far as may be possible from a study of the surface alone, the areas in which oil would be most likely to occur. One of the regions in which it seemed that such investigation would be best repaid is the foothill belt on the west side of San Joaquin Valley near the Coalinga oil field. The Coalinga field, although one of the most productive in California, occupies a relatively small part of this foothill belt, and to casual observers there seems to be no good reason why oil should not be found in other parts of the foothill region and even in the mountainous region farther west, which is underlain in part by many of the formations that underlie the productive Coalinga field. In order to estimate the probable value of the foothills as oil-producing territory, the areas both north¹ and south² of Coalinga along the border of the valley were examined, and the conclusions reached are given in reports already published. The mountainous region farther west, which seemed less promising, has until recently received scant attention, but during part of the summer and fall of 1913 an area extending from the western border of the Coalinga field across the Diablo Range to the low foothills on the east side of Salinas Valley was examined. The present report gives the results obtained in this examination. The immediate reason for the investigation was the need of geologic data for the classification

¹ Anderson, Robert, Preliminary report on the geology and oil prospects of the Cantua-Panoche region, California: U. S. Geol. Survey Bull. 431, pp. 58-87, 1911. Anderson, Robert, and Pack, R. W., Geology and oil resources of the western border of the San Joaquin Valley, Cal.: U. S. Geol. Survey Bull. 603 (in preparation).

² Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district, California: U. S. Geol. Survey Bull. 398, 1910.

of the public land in the area that had been withdrawn from all forms of entry because of its possible value as oil land. As a result of the examination large areas of unappropriated public land have been restored to entry.

The chief conclusion reached regarding the occurrence of oil is that most of the region shown on the map does not offer reasonable promise of yielding petroleum and that much of it is certainly barren of oil. In general, the conditions that make it impossible to consider a large part of the region a prospective oil field are the lack of a sufficient amount of material that might reasonably be considered an original source of petroleum and the absence of a structure which would aid in the concentration of such petroleum as may occur in minute quantities throughout the rocks. In much of the region the Franciscan formation, of probable Jurassic age, which lies stratigraphically below any known oil-bearing beds in the Coast Ranges, either appears at the surface or is overlain by only a thin veneer of Tertiary rocks. Moreover, where Tertiary rocks occur they are usually closely folded and faulted and do not offer the same opportunity for the accumulation of oil as the broadly folded strata along the foothills. In parts of the region oil sands evidently occur beneath the surface, but in no part does it seem probable that any very extensive oil field awaits development. The most promising areas, which lie mainly along the western boundary of the region shown on the map, and also other areas in which the possibility that oil occurs is more slight are discussed under the heading "Local areas" (pp. 139-152).

The geology of the region is described briefly, stress being laid chiefly upon features that are believed to have some bearing on the occurrence of petroleum. Of necessity, therefore, it is impossible to discuss here many interesting geologic features that were brought out in the course of the work, such as the accurate correlation of the various formations with those of other regions and the intricate structure along the San Andreas fault. Moreover, in parts of the region, especially in the vicinity of the San Andreas fault, the structure is so complex and the distribution of the formations is so irregular that much of the detail brought out in the field work can not be shown, so that many generalizations have been made in depicting the areal geology on a black and white map of the scale of that accompanying this report. In order to show more clearly the relation between the geology in parts of this region and that about Coalinga, the areal geology of a small portion of the district described in the Coalinga report¹ is reproduced on the map (Pl. V).

¹ Arnold, Ralph, and Anderson, Robert, *Geology and oil resources of the Coalinga district, California*: U. S. Geol. Survey Bull. 398, 1910.

ACKNOWLEDGMENTS.

J. D. Northrop was a member of the field party during the later part of the season, and many of the facts here recorded are taken from his notes.

The writers take pleasure in acknowledging their grateful appreciation of the courtesies extended to them by the officers of the oil companies in furnishing data regarding the wells and by the inhabitants of the region on whose hospitality they had largely to depend in the study of a region so sparsely settled. Special acknowledgment is due to E. A. Starke, of the Standard Oil Co., and to G. C. Gester, geologist for the Kern Trading & Oil Co.

Before this investigation was undertaken very little work had been done on the geology of the area, almost the only published accounts dealing with it being the brief note by Eldridge on the asphalt deposit near Lonoak¹ and incidental mention of various general features in a paper by Homer Hamlin on the water resources of Salinas Valley.² Besides these accounts a few unpublished notes by Eldridge and Hamlin have been available.

GEOGRAPHY.

The area studied in detail and shown on the map lies about 140 miles southeast of San Francisco and forms a strip 40 miles long and 11 to 14 miles wide, extending northwest and southeast diagonally across the Diablo Range. It includes about 500 square miles in the southern parts of Fresno and San Benito counties and in the eastern part of Monterey County. Coalinga, at the eastern end of the area, is the terminus of a branch of the valley line of the Southern Pacific Co. From Coalinga one of the main wagon roads through the Diablo Range leads up Waltham Valley to Priest Valley and thence down the valleys of Lewis and San Lorenzo creeks to King City, in Salinas Valley. A branch road leaving the main road above Alcalde Canyon leads south across Jacalitos Creek to Parkfield, and other branch roads pass through Peachtree Valley to the Stone Canyon coal mine and up Bitterwater Valley to the valley of San Benito River. A 6-inch pipe line, owned by the Associated Oil & Transportation Co., passes through Waltham, Priest, Lewis Creek, and Bitterwater valleys, and through it oil is pumped from Coalinga to Monterey.

The eastern edge of this belt includes Pleasant Valley, which lies in the foothills that border San Joaquin Valley, at an elevation of about 650 feet above the sea. The southwestern part of the area mapped includes the low hills that border Salinas Valley, which has

¹ Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 407-410, 1901.

² Hamlin, Homer, Water resources of Salinas Valley, Cal.: U. S. Geol. Survey Water-Supply Paper 89, 91 pls., 12 pls., 1904.

an elevation of about 400 feet and lies 6 to 10 miles to the southwest. Between these two foothill belts the mountainous part of the Diablo Range rises gradually to altitudes of over 4,000 feet. The culminating points in this part of the range are Hepsedam, which stands 4,496 feet above the sea; Center Peak, 4,539 feet; and Smith Mountain, 3,967 feet.

Here as elsewhere the range is an almost perfect reflection of the structure. It is not composed of a single ridge but of a number of somewhat broken parallel ridges that separate relatively narrow valleys. These ridges trend obliquely to the course of the main range and are determined by pronounced folds or faults. Parts of two such ridges lie in the area shown on the map. One extends from Smith Mountain northwestward to and beyond Charley Mountain and separates Waltham and Priest valleys from Peachtree Valley and Slack Canyon. The other extends from Sherman Peak through Center Peak to a point north of Hepsedam and separates Bitterwater, Priest, and Waltham valleys from the drainage basins of Los Gatos Creek and San Benito River. The divide which separates the waters that drain into Salinas Valley from those that empty into San Joaquin Valley and which may therefore be considered the crest of the Diablo Range cuts directly across these ridges. Priest and Charley valleys are two small faulted synclinal valleys that lie practically at the crest of the range. Both lie in the Salinas drainage basin, but both are being rapidly cut away by streams of high gradient that drain eastward into San Joaquin Valley.

The climate is dry and hot in summer, particularly on the eastern slope of the range. A few of the larger streams carry water throughout the year, but most of them are intermittent, and nearly all the water contains sufficient salts to make it unpalatable. A few of the springs, however, particularly those in the Franciscan formation and in the coarse conglomerate of the Cretaceous, furnish excellent water. In order to obtain boiler water for the pumping stations along the pipe line of the Associated Oil & Transportation Co., several of the better springs have been developed and the water piped for many miles. The main supply comes from a number of springs near Hepsedam which furnish the water for two stations on Lewis Creek and one at the head of Bitterwater Valley.

The plains and lower hills are bare except for a sparse growth of sagebrush and short grass. The mountainous part is more or less covered by chaparral, but the growth is rarely thick enough to be impassable. A light growth of small pine and manzanita is common on the outcrops of diatomaceous shale, and oaks are scattered throughout the region.

The amount of level ground suitable for agriculture is small, and the country is used generally as a cattle range, for despite the dry

climate there is a good growth of grass in wet seasons. In Bitterwater, Priest, and Peachtree valleys and in some of the small valleys tributary to Salinas Valley several thousand acres are dry farmed; and on San Lorenzo Creek, both near Lonoak and just west of the area shown on the map, small areas of alfalfa are under irrigation.

GEOLOGY.

DISTRIBUTION AND GENERAL RELATIONS OF THE ROCKS.

The area shown on the map (Pl. V), forming a narrow belt that extends across the Diablo Range, does not present a single type of structure but is divided by the San Andreas fault into two parts, which are so distinct, both structurally and stratigraphically, that they may almost be regarded as distinct geologic provinces. The difference in the stratigraphic section exposed in the two parts of the region may be seen by comparing the two columnar sections (figs. 3 and 4). Southwest of the fault are the foothills that border Salinas Valley, and northeast of it is the main Diablo Range. This range may also be considered as composed of two parts—the central mountain mass, an area of many short irregular folds and faults, and the eastern foothills, an area in which the rocks are flexed into a few broad folds. This separation is indefinite, however, as the structure becomes gradually more complex westward from the edge of San Joaquin Valley toward the mountains, and a sharp line of division, such as that of the San Andreas fault, is nowhere apparent.

On the southwest side of this fault much or probably all of the region is underlain at no great depth by granitic rocks. These rocks are exposed only in small areas in the northwest corner of the region mapped, but farther north they appear at the surface for about 40 miles and form the Gabilan Range. Resting upon the eroded surface of this granitic mass are late Tertiary sand, clay, and diatomaceous shale. These beds, although tilted to low angles whose direction of dip is somewhat irregular, disclose few well-marked folds. The lower part of these late Tertiary beds is believed to be the equivalent of the Santa Margarita formation (middle Miocene), which is typically developed in the upper end of Salinas Valley, some 40 miles to the south. Their upper part, represented mainly by relatively thin deposits of gravel and clay on the flat-topped ridges, is correlated with the Tulare formation (Pliocene).

Northeast of the San Andreas fault granite does not appear, and the oldest rocks are those of the Franciscan formation (Jurassic?). As mapped, this formation comprises a rather heterogeneous mass of more or less altered sedimentary rocks and various igneous rocks that are intruded into them. Strictly speaking the igneous rocks are not a part of the Franciscan, but for convenience in the present discussion

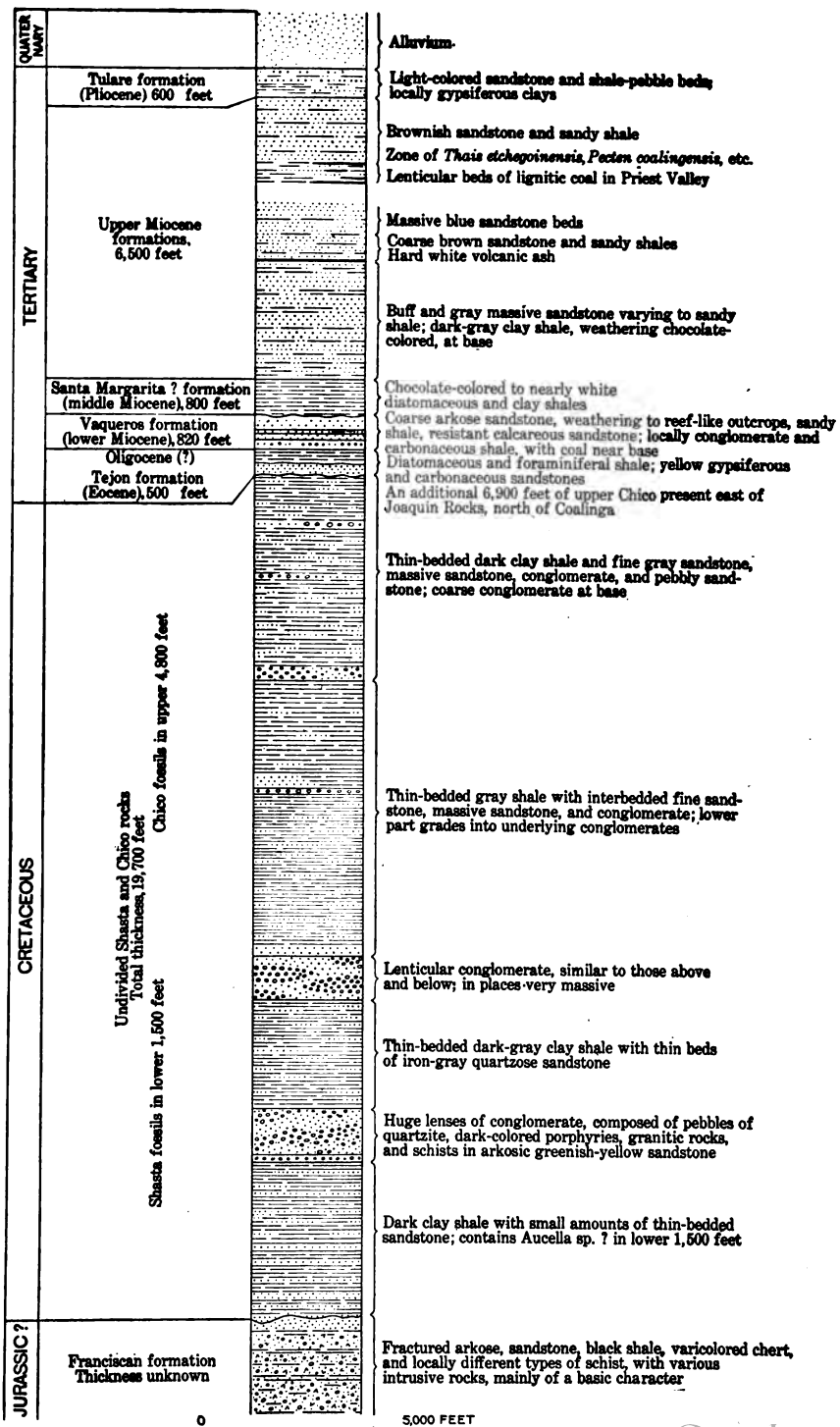


FIGURE 3.—Columnar section of rocks northeast of the San Andreas fault, central California.

the two are represented on the map and discussed together. Resting unconformably upon the Franciscan formation are dark clay shale, sandstone, and coarse conglomerate which represent both Lower and Upper Cretaceous. Eocene and Oligocene rocks are absent west of the Coalinga district, and the Vaqueros formation (lower Miocene) rests upon the Cretaceous or older rocks with marked unconformity. The Vaqueros formation is in turn overlain unconformably by a body of diatomaceous shale, whose equivalent was termed the Santa Margarita (?) formation¹ in the Coalinga report. For convenience, and also to show its equivalence to the shale in the region south of Coalinga, the same name is used here. The later Tertiary rocks, which overlie the Santa Margarita (?) formation with probable unconformity, comprise a great mass of clay shale, brownish and bluish sandstone, and conglomerate. The lower part of this series of beds is the equivalent of the Jacalitos and Etchegoin formations, which

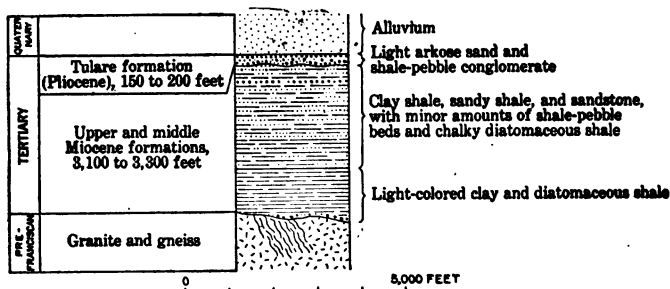


FIGURE 4.—Columnar section of rocks southwest of the San Andreas fault, central California.

occur along the foothills near Coalinga; the upper part, which is distinguished from the lower by its abundant pebbles of diatomaceous shale, is the equivalent of the Tulare formation (Pliocene) of the Coalinga district and the area farther east.

In mapping the area between the San Andreas fault and the Coalinga district the formations younger than the Vaqueros and older than the Tulare were grouped into two divisions. The lower division embraces the diatomaceous shale that was described in the Coalinga report as the Santa Margarita (?) formation; and the upper division, which is termed the upper Miocene, comprises the Jacalitos and Etchegoin formations. The grouping of the formations into these map units has been adopted in order that the areal distribution of the diatomaceous shale might be shown, as it has a bearing on the possible occurrence of oil.

In the area west of the San Andreas fault the diatomaceous shale is so irregularly distributed that no attempt has been made to show it

¹ U. S. Geol. Survey Bull. 398, p. 88, 1910.

separately on the map. It has therefore been grouped with the overlying fossiliferous sands, which are regarded as the equivalent of the typical Santa Margarita and which are shown on the map as part of the upper Miocene.

GRANITIC ROCKS.

Granitic and associated schistose rocks are exposed in the western part of the region in small areas from which the overlying Tertiary beds have been eroded and along the San Andreas fault zone, where a small block of granite is faulted up against the late Tertiary. These rocks form part of a mass upon which the Tertiary beds rest in much or possibly all of the Salinas Valley. Granite rocks, evidently part of this same mass, outcrop in extensive areas in the Gabilan Range, whose south end lies about 10 miles west of Bitterwater Valley, and also in the Santa Lucia Range, on the west side of Salinas Valley. The granitic and associated schistose rocks in the Santa Lucia Range have been termed by Willis¹ the Coast complex. The age of the granite is not definitely known, but many geologists who have worked in the Coast Ranges believe that it is the equivalent of the granite in the Sierra Nevada and it is presumably of Jurassic age. In the area mapped the granite is in contact only with late Tertiary sedimentary beds which have been deposited upon it.

JURASSIC (P) SYSTEM.

FRANCISCAN FORMATION.

The oldest sedimentary rocks in this part of the Diablo Range are those which occur in irregular areas in the central part of the range and which are mapped as the Franciscan formation. These rocks are of a variety of lithologic types, ranging from relatively little altered arkosic sandstone and shale to different kinds of schist, of which bluish glaucophane schist is prominent. Probably the type of rock that appears most abundantly is a very arkosic sandstone, much fractured and seamed with calcite. Small masses of gray limestone occur sparingly, but thin-bedded reddish and greenish chert is abundant and weathers characteristically to prominent ragged outcrops. These sedimentary rocks are intruded by various igneous rocks, mainly of rather basic character, which are largely altered to serpentine, although locally the intrusive rocks are fairly fresh and unaltered. The relatively unaltered character of the rocks is particularly noticeable near Hepsedam, where there is a considerable area of rather coarse textured, little altered granitoid rock, composed predominantly of hornblende and feldspar. The intrusive rocks, although clearly younger than the sedimentary beds and not a

¹ Willis, Bailey, Geol. Soc. America Bull., vol. 11, p. 419, 1900.

part of the Franciscan, have been grouped with them in the mapping as the Franciscan formation.

The granitic rocks and the Franciscan formation are nowhere in contact in this region and definite evidence regarding their relations can not be offered. However, Fairbanks¹ has described the Franciscan rocks as resting unconformably upon the eroded surface of the "Coast complex" at Slates Springs, on the west side of the Santa Lucia Range. As the various exposures of granite appearing about Salinas Valley are believed to be parts of one mass, the Franciscan rocks in the Diablo Range must be considered younger than the granite exposed west of the San Andreas fault. The Lower Cretaceous (Shasta series) is evidently unconformable upon the Franciscan. It shows fewer fractures and none of the results of metamorphism which the Franciscan rocks exhibit, and in most of the region it may be differentiated readily from the older rocks. Along the San Andreas fault zone, however, the two formations are so fractured and intermingled that in the absence of fossils in the younger they appear to be indistinguishable.

CRETACEOUS SYSTEM.

Overlying the Franciscan formation unconformably is a succession of beds of dark clay shale, arkosic sandstone, and conglomerate, which, in the area mapped, have an aggregate thickness of over 19,000 feet. This succession of strata embraces both the Shasta series (Lower Cretaceous) and the Chico formation (Upper Cretaceous). Farther north, along the east flank of the Diablo Range, about 12 miles north of Coalinga, Cretaceous beds having a total thickness of at least 6,900 feet overlie the youngest Cretaceous beds exposed in the area shown on Plate V, giving a thickness of approximately 25,900 feet for the Cretaceous section in the southern part of the Diablo Range. In many places the Cretaceous beds, especially those belonging to the Shasta series, resemble somewhat the sedimentary beds in the Franciscan formation. The two terranes are evidently unconformable, however, for the Franciscan is much folded, faulted, and locally metamorphosed and is intruded by a multitude of igneous rocks, whereas even the lowest beds of the Shasta are much less fractured, are unmetamorphosed, and in this region are intruded by few if any igneous rocks. The unconformity between the youngest Cretaceous formation in this region and the oldest Tertiary in contact with it is clearly shown by the absence of many thousand feet of beds in the Upper Cretaceous and early Tertiary which are exposed in hills north of Coalinga.

¹ Fairbanks, H. W., *Stratigraphy at Slates Springs*: Am. Geologist, vol. 18, pp. 350-353, 1894.

The Cretaceous section is best developed on the north side of Waltham Valley, where alternating beds of clay shale, arkosic sandstone, and conglomerate of variable thickness form a northward-dipping monocline. In the report on the geology of the Coalinga district the Cretaceous rocks were described as embracing three divisions, an upper, middle, and lower, the last two of which are well developed in the region described in the present report. (See Pl. V.) The line of separation between these two is the base of a massive conglomerate which outcrops near the crest of Juniper Ridge. The lower division, which is exposed southwest of that ridge, is about 14,900 feet thick. Although the lithologic changes in most of this division are so numerous both vertically and along the strike that it is difficult to separate it into well-defined members, it may for convenience be described as being composed of two parts. The lower part embraces about 3,500 feet of a dark-gray clay shale that weathers to light greenish gray, interstratified with sandy shale and numerous thin beds of fine-grained iron-gray quartzitic sandstone. This part is best exposed southwest of Center Peak, where it rests, apparently in unfaulted contact, upon the Franciscan.¹ The upper part comprises about 11,400 feet of interstratified clay shale like that in the lower part, sandy shale, massive sandstone, and conglomerate. The conglomerate, whose presence distinguishes the upper from the lower part of the division, is lenticular, in places reaching a thickness of about 1,200 feet and in places thinning and grading laterally into sandstone. The pebbles are well rounded and the largest measure about 8 inches in diameter. They are composed of quartzite, dark-colored porphyritic rock, and granitic rock and are embedded in a matrix of dark-greenish sandstone that weathers reddish brown. Between Waltham Valley and Los Gatos Creek the upper part of the lower division contains two prominent lenses of conglomerate. The lower lens, which has a maximum thickness of about 1,200 feet, forms the crest of Center Peak, from which it extends southeastward as a prominent ridge that trends nearly parallel to Juniper Ridge, on the west side of the canyon in which Fresno Hot Springs is situated. About 2,500 feet above this conglomerate and separated from it by interstratified clay shale and sandstone is another lens of coarse material which forms the ridge east of Fresno Hot Springs. Between this conglomerate and that which forms the base of the middle division are sandy shale and sandstone.

The middle division includes the conglomerate exposed along Juniper Ridge and a succession of clay shales and sandy shales that

¹ Owing to errors in the preparation of the map the Franciscan rocks in this area are shown as the Santa Margarita (?) formatiton, and in the geologic section on the map the two parts of the lower division of the Cretaceous system are termed the lower and middle divisions, and the middle division is termed the upper division.

overlie it. In the report on the Coalinga district¹ the thickness of this division exposed on Alcalde Creek is given as 4,800 feet. This division of the Cretaceous is exposed also north of Coalinga, where, on the east flank of the Coalinga anticline northeast of the Joaquin Rocks, it is overlain by about 5,300 feet of massive concretionary sandstone and dark clay shale, upon which rest about 1,600 feet of shale filled with the remains of diatoms and foraminifers. These two last-mentioned members constitute what was described in the Coalinga report as the "upper member of the Knoxville-Chico rocks."

About 1,500 feet above the base of the lower division were found abundant specimens of *Aucella crassicolis* (?), a fossil typical of the Lower Cretaceous. As there appears to be no marked lithologic or stratigraphic break in the lower 3,500 feet of the Cretaceous section—that is, up to the conglomerate that separates the two parts of the lower division—it seems probable that all of this part of the lower division is of Lower Cretaceous age. Upper Cretaceous fossils have been found in the middle of the three divisions northeast of Juniper Ridge, and the conglomerate at the base of that division was described in the Coalinga report as the probable base of the Upper Cretaceous. Only two fossils have yet been found in the upper part of the lower division. These, which were found near the top of the conglomerate that separates the two parts of the lower division, although not diagnostic, suggest Upper Cretaceous rather than Lower Cretaceous age, so that the line between the Shasta and Chico may occur at the base of the conglomerate that extends southeastward from Center Peak, instead of at the base of the conglomerate that appears at the base of the upper division along Juniper Ridge, as was suggested in the report on the Coalinga district.¹

The Cretaceous near Jacalitos Creek and along the San Andreas fault zone consists largely of dark clay shale of Lower Cretaceous age, in which *Aucella crassicolis* (?) is fairly abundant. Only a few of the areas of Cretaceous that occur along the south side of Waltham and Lewis creeks have been shown, many small areas having been grouped in the mapping with the Franciscan.

Upper Cretaceous rocks are unknown south of Waltham Valley within the boundary of the area shown on Plate V. Rocks of that age occur, however, in a small area at the crest of the Diablo Range about a mile north of the Stone Canyon coal mine.

TERTIARY SYSTEM.

EOCENE AND OLIGOCENE (?) SERIES.

Early Tertiary rocks are but sparingly represented in the area mapped, outcropping only in a narrow belt some 3 miles in length

¹ Arnold, Ralph, and Anderson, Robert, Geology and oil resources of the Coalinga district: U. S. Geol. Survey Bull. 398, p. 53, 1910.

in the foothills west of Coalinga. Near the San Joaquin Valley coal mine these beds, which were mapped as the Tejon formation in the report on the Coalinga district¹ but which include probable Oligocene as well as true Tejon, rest unconformably upon the Cretaceous and are overlain unconformably by the Vaqueros formation. The beds consist of about 200 feet of whitish gypsiferous and carbonaceous Eocene sandstone (the true Tejon) overlain by white diatomaceous and foraminiferal shale of probable Oligocene age. These beds outcrop for many miles to the north in the foothills bordering San Joaquin Valley, where the shale is at least 1,000 feet thick. They also continue to the south, probably underlying much of the area where late Tertiary rocks appear at the surface south of Coalinga, and outcrop along the flank of Reef Ridge, southeast of the area shown on the map (Pl. V). The Oligocene (?) diatomaceous shale overlying the Tejon formation (Eocene) is of economic importance, as it is probably the ultimate source of most of the petroleum in the Coalinga field.

MIOCENE SERIES.

VAQUEROS FORMATION (LOWER MIOCENE).

The oldest Tertiary formation that has any considerable areal distribution in the region mapped is the Vaqueros formation, which is composed mainly of massive sandstone that contains a good marine fauna of lower Miocene age. It outcrops in the foothills west of Coalinga; in irregular areas in the mountainous part of the range, mainly south of Waltham and Priest valleys; and in a narrow belt, about a mile in length, northeast of Priest Valley. It doubtless occurs also beneath the later Tertiary formations in parts of Waltham and Priest valleys, but its extent there is a matter of conjecture. Lower Miocene rocks do not outcrop west of the San Andreas fault within the area shown on Plate V. The Vaqueros occurs, however, in a narrow fault block within the San Andreas fault zone southwest of the Stone Canyon mine, and farther southeast in the Parkfield region it is reported by Eldridge² on the southwest side of the fault zone.

In the foothills west of Coalinga this formation overlaps unconformably the Oligocene (?) diatomaceous shale, and elsewhere in the area mapped it rests with marked unconformity upon either the Franciscan or the Cretaceous rocks. Resting unconformably upon the Vaqueros is a body of diatomaceous shale that is mapped as the Santa Margarita (?) formation. The unconformity between these formations is well shown in the central part of the range by the irregular way in which the Santa Margarita (?) overlaps the Va-

¹ U. S. Geol. Survey Bull. 398, pp. 62-75, 1910.

² Eldridge, G. H., unpublished notes.

queros. The relationship is most clearly shown on the west side of Deep Well Canyon, where the two formations show a discordance in dip of over 20° and the basal sandstone of the Santa Margarita (?) lies on the eroded edges of the Vaqueros. The unconformity is also indicated in the syncline north of Smith Mountain, where the line along which the Vaqueros is folded is offset from that along which the Santa Margarita (?) is folded.

Neither the lithology nor the thickness of the Vaqueros is constant, and although the variation in thickness is partly due to erosion subsequent to deposition and the removal of the upper part of the formation, it is also partly due to the fact that the formation was laid down upon a very irregular surface and that in consequence the lowest beds were not everywhere deposited.

The Vaqueros is probably most completely exposed near the crest of the range southeast of Smith Mountain, where it has a thickness of about 820 feet. The lower 200 feet or so is composed of carbonaceous shale, containing beds of coal and a conglomerate and coarse sandstone, made up largely of fragments of Franciscan rocks. Above this is about 220 feet of very resistant calcareous sandstone that forms the crest of the castellated ridge of which Smith Mountain and Smith Pinnacles are parts. Overlying the calcareous sandstone and forming the upper part of the Vaqueros are about 400 feet of alternating hard and soft sandstones. The more resistant beds weather out prominently and in places where the overlying softer beds have been stripped off form broad, bare dip slopes 400 feet or more in length. The presence of such resistant reef-like beds as these is one of the most characteristic features of the Vaqueros in the southern part of the Diablo Range.

On Lewis Creek the Vaqueros contains a considerable amount of pinkish shale, probably diatomaceous, which is similar to that in the overlying Santa Margarita (?), and the two formations are separable with difficulty.

SANTA MARGARITA (?) FORMATION (MIDDLE MIOCENE).

Resting unconformably on the Vaqueros is a formation composed of 700 to 800 feet of purplish to gray diatomaceous and clay shale which weathers to pinkish-white or chocolate-colored outcrops. This formation is practically continuous in outcrop and varies little in lithology from the north side of Lewis Creek to the southeast corner of the area shown on the map and for about 25 miles farther south along Reef Ridge. In the report on the geology and oil resources of the Coalinga region this shale was described as the probable equivalent of the Santa Margarita formation. In order to show its equivalence to the shale south of Coalinga, the name Santa Margarita (?) is used in the present discussion.

Where the Santa Margarita (?) is best exposed the lower 15 to 40 feet is a massive arkosic sandstone lithologically like that in the Vaqueros formation. Above this lower sandstone is from 200 to 800 feet of hard and brittle diatomaceous clay shale which breaks with a splintery fracture and weathers pink or nearly white. The shale forms little or no soil and weathers to steep ridges and knobs which are recognizable at considerable distances by their chalky-white or pinkish color and by the light growth of pine and manzanita which they support. Toward the top the shale gradually becomes more clayey and grades into a dark-gray clay shale which weathers to platy chocolate-colored fragments and forms a clay soil. This change does not seem to take place along an exact stratigraphic line, but from place to place one facies increases in thickness at the expense of the other. No evidence of unconformity between the diatomaceous shale of the Santa Margarita (?) formation and the sandy beds of the upper Miocene was found, the line of contact being drawn at the horizon where the shale becomes sandy rather than clayey and weathers yellowish brown rather than purplish.

UPPER MIOCENE FORMATIONS.

Distribution and character.—Numerous beds of sandstone, conglomerate, and diatomaceous and clay shale that were deposited during the later part of the Miocene have been grouped together in the mapping as “chiefly upper Miocene.” These beds occur on both the northeast and southwest sides of the San Andreas fault, but they are not precisely the same in character nor exactly equivalent stratigraphically in the two areas. Most if not all of the rocks thus mapped southwest of the fault are regarded as the equivalent of the Santa Margarita formation and therefore as of middle Miocene age. Those northeast of the fault constitute the westward continuation of the Jacalitos and Etchegoin formations (upper Miocene) in the Coalinga region and, in the lower part, embrace some beds of probable Santa Margarita (middle Miocene) age. The reasons for grouping the formations in this manner in the geologic mapping is explained in the general statement about the geology. (See p. 125.) The Jacalitos and Etchegoin formations are believed to be in the main younger than the true Santa Margarita, although the fauna contained in the lower part of what is mapped as upper Miocene in Waltham Canyon shows a close similarity to that of the true Santa Margarita. It should also be noted that the diatomaceous shale in the lower part of the beds mapped as upper Miocene west of the fault may be the correlative of the shale mapped as the Santa Margarita (?) formation east of the fault. A full discussion of the possible relationship of these formations can not be given here nor can a decision be reached until careful paleontologic study is made.

Area southwest of the San Andreas fault.—Between the San Andreas fault and Salinas River the granite is overlain by beds of shale and sandstone, which contain marine fossils characteristic of the Santa Margarita formation and which in the area mapped have a maximum thickness of about 3,300 feet. Near Lonoak the lower 800 to 1,000 feet is composed largely of diatomaceous and clay shale which weathers to a light-pink or chocolate color and which contains relatively little interstratified sand, although the lower part is in some places somewhat sandy and in a few places, as at the asphalt quarry west of Lonoak, is a coarse arkosic grit. This shale resembles closely the "chalky" shale of the Monterey group. It was described as Monterey shale by Eldridge,¹ but as the writers discovered in it fossils that are believed to be characteristic of the Santa Margarita formation, they have grouped it in the present report with the overlying more sandy beds. Shale of this type has a somewhat local distribution in the area mapped, apparently grading along the strike into sandy shale and sandstone. Overlying the diatomaceous shale near Lonoak is about 1,100 feet of sandy shale, above which is about 1,200 feet of sandy shale and fine-grained clayey sandstone containing thin beds of diatomaceous shale and of conglomeratic sandstone filled with pebbles of white flinty shale. The interbedded shale in the upper 1,200 feet is very light colored and "chalky" and is perhaps partly volcanic ash. Although occurring in beds only a few feet thick, interstratified with sandstone, it is almost free from coarse material. Marine fossils are abundant in the upper part of the formation, the large barnacle *Tamiosoma gregaria* being exceptionally common in the uppermost 1,000 feet.

Area northeast of the San Andreas fault.—Northeast of the San Andreas fault is a succession of beds of sandstone, sandy shale, and conglomerate, which in the hills west of Coalinga is separated into the Jacalitos and Etchegoin formations but which in the rest of the area is mapped with the upper Miocene. These beds rest upon the diatomaceous shale of the Santa Margarita (?) formation, into which they seem to grade, and the line of separation has been drawn arbitrarily so that the predominantly shaly beds are included in the Santa Margarita (?) and the predominantly sandy beds in the upper Miocene. The line between the upper Miocene and the Tulare formation (Pliocene) is only a little more definite and has been drawn at the base of the beds which contain abundant pebbles of diatomaceous shale.

In the upper part of Waltham Valley the upper Miocene beds have a maximum thickness of about 6,500 feet. The lower 500 to 600 feet is mainly sandy shale that weathers yellow or brown and shaly

¹ Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, p. 408, 1901.

sandstone, above which is about 2,800 feet of buff, brown, and greenish-yellow sandstone and shaly sandstone with a little coarse grit and conglomerate. Thin beds of white ash occur at irregular intervals in the upper 1,000 feet of this member, the most prominent being a bed 10 to 20 feet thick that occurs about 2,700 feet above the top of the Santa Margarita (?) formation. The buff sandstone grades upward into beds, less than 600 feet thick, of massive coarse-grained white and blue sandstone interbedded with fine sandstone. Above the blue sandstone is about 900 feet of brown sandstone and sandy and carbonaceous shales. In Priest Valley the upper 425 feet of this member contains lignitic sandy brown shale, in which occur beds of low-grade coal that have been prospected at a few places. Above the carbonaceous beds massive gray and buff sandstone and clayey sands alternate for 1,500 feet up to the beds containing shale pebbles, which form the base of the Tulare.

TULARE FORMATION (PLIOCENE).

The youngest formation in this region that has suffered marked deformation is composed of beds of rather poorly consolidated sandstone, shale, and conglomerate, which were deposited either in lakes or subaerially. On account of similarity in lithologic character and in stratigraphic position this formation is correlated with the Tulare formation, which is typically exposed in the Coalinga region. In at least part of the Priest Valley region it lies unconformably upon the underlying upper Miocene formations just described, and throughout the region it is overlain with marked unconformity by the flat-lying Quaternary deposits. Beds correlated with the Tulare are exposed in three general areas—(1) in the Priest Valley syncline, (2) along the San Andreas fault zone, and (3) on the foothills west of Peachtree Valley, in the center of the Peachtree syncline, and northwest of the area mapped.

In the southern part of Salinas Valley is the Paso Robles formation, which consists in part of fresh-water beds similar in lithologic character to the Tulare and probably of the same age, but work done near the type locality by Robert Anderson indicates that there is a lower marine member of the Paso Robles, which is the representative of the Etchegoin formation of the Coalinga region, and for this reason the name Tulare is used for the purely fresh-water beds of the Priest Valley and neighboring regions.

The lithology and thickness of the Tulare varies considerably in the different areas. In the Priest Valley syncline it comprises not less than 500 to 600 feet of incoherent light-colored, poorly sorted angular, distinctly arkosic sandstone and conglomerate. Pebbles of diatomaceous shale like that in the Santa Margarita (?) formation

northeast of the San Andreas fault and in the Monterey group west of the Salinas Valley are very common in the conglomerate. These beds weather to light-gray outcrops that contrast markedly with the brownish color that is characteristic of the upper Miocene. There is no sharp change in lithology between the upper Miocene and the Tulare, and the line of contact has been drawn at the base of the beds which contain abundant pebbles of diatomaceous shale. This gradual change in lithology and the lack of any structural evidence of interrupted sedimentation suggest that the formations are conformable here. Also in much of Waltham and Priest valleys a fossiliferous zone containing characteristically *Pecten coalingensis*, *Pecten wattsi*, and *Thais ethegoinensis* occurs at about the same stratigraphic distance below the base of the Tulare, suggesting that an unconformity, if present, does not represent an important interval of erosion.

In the San Andreas fault zone the Tulare formation is composed of coarse arkose and shale pebble beds like those described above and in addition contains red and green clays, in which there are numerous beds of gypsum. The unconformity between the Tulare and the upper Miocene formations is shown by the presence of a conglomerate near Alvarez Creek containing numerous boulders of fossiliferous sandstone of upper Miocene age, the equivalent of the Jacalitos or Etchegoin formation. Southwest of the San Andreas fault the Tulare comprises a basal bed some 10 to 15 feet thick of indurated shale-pebble conglomerate, above which are incoherent gray sand and sandy clay, the total thickness being not over 150 or 200 feet.

QUATERNARY SYSTEM.

In Quaternary time the Priest Valley region was an area of erosion rather than of deposition, and it therefore contains no large Quaternary deposits. The beds of the larger streams are covered with alluvium, but this material is only a temporary deposit, formed in the course of its transportation beyond the area here described. Southwest of the San Andreas fault alluvium seems to be collecting in the stream beds, and the alluvial deposits on the valley floors are relatively greater in that area than in the area northeast of the fault.

STRUCTURE.

The dominant structural feature in this part of the Diablo Range is the San Andreas fault, which trends diagonally across the region mapped, separating it into two parts, which exhibit two distinct types of structure. The dissimilarity in the stratigraphic record on opposite sides of the fault, or fault zone, as it might more properly be termed, shows that pronounced movements have taken place along

it since at least as far back as middle Miocene time. The movements along the line farther north, which caused the earthquake of April 18, 1906, were almost wholly horizontal, but the lack of the Franciscan, the Cretaceous, and the Vaqueros formation and the presence of granite at or close to the surface in the area west of the fault seem to indicate that there was once very considerable vertical movement along this general zone, the net result of which was an elevation of the mass lying west of the fault relative to that lying east of it. The fault zone varies in width from half a mile to a mile and is composed of a number of approximately parallel fractures, which separate long blocks of the various formations. The line shown on the map as the San Andreas fault is the fracture along which movement seems to have taken place most recently and which may be considered the active fault. This line is marked by numerous small sunken areas, some of which are occupied by lakes throughout the year and which are especially notable along the flat summit of Mustang Ridge.

In the area west of the fault the granite has evidently furnished a foundation sufficiently rigid to prevent more than a minor amount of warping, and the Tertiary beds a short distance west of the fault zone are rarely tilted over 10° and in most places less than 5° , forming short and for the most part irregular folds or domes. The only large fold in this part of the region is the broad, shallow Peachtree syncline, which extends northwestward from a point near the center of the Peachtree ranch for more than 10 miles beyond the boundary of the area shown on the map. The dips on either flank of this fold are so low through most of its course that the precise location of its axis is hard to determine. The dip on both flanks is slightly irregular, and at one place in Bitterwater Valley, just below the mouth of Lewis Creek, a low dip toward the east forms a very short subsidiary anticline in the east flank of the larger syncline.

In the mountainous part of the range northeast of the fault zone the rocks are bent into a multitude of folds and are broken by faults, most of which trend approximately parallel to the San Andreas fault and somewhat obliquely to the course of the Diablo Range. The largest of these folds is the syncline which forms Priest Valley and which extends from it southeastward through the upper part of Waltham Valley. This general synclinal structure continues, although not exactly as an unbroken syncline, farther southeastward past Curry Mountain and merges into the monoclinical structure along the flank of Reef Ridge. In this structural trough Tertiary beds which aggregate in thickness about 8,500 feet have been infolded. On the south the basin is bounded by the mass of Franciscan rocks that, with various infolded and faulted bodies of Cretaceous and Tertiary rocks, forms the ridge on the south side of Waltham

and Priest valleys. On the north side of the basin the Tertiary formations abut against the northward-dipping monocline of Cretaceous rocks. Although the folding is pronounced and the Tertiary beds are in places tilted on edge or are even overturned, yet the forces causing the deformation seem to have spent themselves in a relatively narrow zone and did not greatly affect the Cretaceous beds that lie $1\frac{1}{2}$ to 2 miles from the axis of folding. These Cretaceous beds were evidently tilted before middle Miocene time to approximately their present attitude, as is shown by the fact that in small areas north of Priest Valley and near Alcalde Canyon almost flat Tertiary beds rest upon the steeply dipping Cretaceous rocks. The difference in the character of the foundation upon which the upper Miocene formations rest in the north and south sides of Waltham and Priest valleys suggests that the fold in the Tertiary beds follows an old line of weakness along which the Cretaceous beds were faulted against the Franciscan in pre-middle Miocene time. Between the center of the synclinal basin and the San Andreas fault are numerous areas of Tertiary rocks flexed into short, shallow folds. The synclines are for the most part unbroken, but the anticlines are almost invariably faulted and a narrow belt of Franciscan rocks is exposed.

The complexity of the structure gradually diminishes toward the east, and in the foothills bordering the San Joaquin Valley the Tertiary rocks which appear at the surface form only a few broad folds. In the area shown on the map only the part lying east of Curry Mountain may be said to belong to this foothill belt.

PETROLEUM.

CONDITIONS IN THE COALINGA DISTRICT.

The area discussed in this report lies mainly in the mountainous region west of the Coalinga oil field, one of the largest producing fields in California, and a discussion of the possibility of developing oil in it may well be preceded by a brief account of the occurrence of oil in the productive field.¹

The oil sands in the Coalinga district lie in the midst of a thick mass of sedimentary beds, mainly of marine origin and of Cretaceous and Tertiary age. These beds are mostly sandstone and clay or clay shale, but they include two persistent formations which are filled with the remains of minute organisms—diatoms and foraminifers—and which are commonly termed diatomaceous shales. One of these formations lies at the top of the Cretaceous and the other in the lower part of the Tertiary, and in much of the region the two are separated by many hundred feet of sandstone and shale. With one exception the oil-bearing sands may be grouped in two

¹ For a full discussion of the Coalinga district see U. S. Geol. Survey Bull. 398, 1910.

zones, one including the sandy beds immediately overlying, underlying, and intercalated with the lower (Cretaceous) shale, the other comprising the sands that have a similar relation to the upper (Tertiary) diatomaceous shale. The single exception to this grouping is an oil sand which occurs in the sandstones and shales and which lies between the two diatomaceous shale formations but is separated from each of those formations by several hundred feet of barren strata. The upper of the two main zones is by far the more productive, and from the sands overlying the Tertiary diatomaceous shale comes more than 99 per cent of all the oil produced in the Coalinga district. The close association of oil-bearing sands and diatomaceous shales is not unique in the Coalinga region but is the one practically constant feature that may be recognized in all the productive oil fields in the southern half of California. This constant relation has led to the belief that most if not all of the petroleum in the southern half of the State had its origin in the diatomaceous shales. The sandstones in contact with the diatomaceous shales are not everywhere petroliferous; they contain oil in quantity only in places where structural and other conditions have caused it to accumulate. In the Coalinga district the main accumulations lie along a broad anticlinal fold that extends southeastward from the Diablo Range, forming an outlying range of hills east of the town of Coalinga, and also at the upper end of the plunging syncline that lies between the anticline and the main range. In general it may be said that structures of this type appear to govern the occurrence of petroleum in most of the productive fields in the southern half of California. Petroleum is usually found in the anticlinal folds, but in many places, especially along the west side of San Joaquin Valley, oil occurs also in the synclines that parallel anticlines in which the sands are saturated with petroleum.

With this general idea of the manner in which oil occurs at Coalinga in mind the broader features of the region west of Coalinga will be considered to show how far the conditions existing at Coalinga are duplicated.

CONDITIONS IN WALTHAM, PRIEST, BITTERWATER, AND PEACHTREE VALLEYS.

The San Andreas fault divides the region west of Coalinga into two parts, whose structure is so diverse that they may best be treated separately even in this general discussion.

In the mountainous region between the San Andreas fault on the west and the Coalinga district on the east neither of the diatomaceous shale formations with which the oil sands of the Coalinga district are associated occurs. There is present, however, a younger formation of precisely the same type, in which oil might have been formed equally as well as in either of the older shales at Coalinga. Indeed,

this shale, which is shown on the map as the Santa Margarita (?) formation, continues southeast and forms part of the huge body of shale from which the oil obtained in the Temblor Range fields is believed to have been derived. The structure in the mountainous region west of Coalinga is, however, very unlike that in the foothills, and the Tertiary rocks, instead of being folded into broad anticlines and synclines as they are along the eastern margin of the Diablo Range, are sharply flexed and faulted and occur in more or less isolated blocks resting on the older formations. Thus the structure is in general not favorable for the collection of oil that may have been derived from the diatomaceous shale, and a duplication of the conditions existing in the Coalinga field is not to be expected. There is a slight chance that oil may have collected beneath a small area lying south of Curry Mountain, but it seems improbable that much oil has concentrated there. Besides the diatomaceous shale there is in this part of the region another mass of sedimentary rocks that must be considered a possible source of petroleum. This mass comprises the dark-colored compact clay shale containing traces of carbonaceous matter that lies in the lower part of the Cretaceous and is especially well exposed on the north side of the upper part of Waltham Valley. This dark clay shale is very like the shale in Colusa and Glenn counties, in northern California, in which seeps of oil occur. However, throughout the region the Cretaceous shale is steeply tilted and nowhere has an attitude favorable for the collection of petroleum.

In the foothills west of the San Andreas fault the lower part of the Tertiary formation contains masses of diatomaceous shale that reach thicknesses of several hundred feet. Asphalt and dry oil sand occur associated with the shale, and this area of low dip should be critically examined as one in which petroleum might have accumulated.

LOCAL AREAS.

AREA SOUTH OF CURRY MOUNTAIN.

GEOLOGY AND ECONOMIC POSSIBILITIES.

In the area of relatively low relief near the southeast corner of T. 21 S., R. 14 E., between the upper part of Jacalitos Creek and Curry Mountain, several structures merge, and, although the dominant feature is the general synclinal structure that produces Waltham Valley, the rocks are folded into a number of small irregular anticlines and synclines. The beds appearing at the surface are of late Miocene age. The older Tertiary beds, which were mapped in the Coalinga report¹ as the Santa Margarita (?), Vaqueros, and Tejon formations, appear to the southeast along Reef Ridge; but to the northwest, about Curry Mountain, the later Miocene strata rest directly upon the Cretaceous, and the older Tertiary formations are not

¹ U. S. Geol. Survey Bull. 398, 1910.

exposed anywhere between that place and Alcalde Canyon. The oil obtained in the main Coalinga field is believed to have originated in the diatomaceous shale which in the Coalinga report was mapped as the upper part of the Tejon formation but has since been proved to be younger than Tejon and probably of Oligocene age and to have migrated from that shale into the sandstones that immediately underlie, overlie, or are bedded with it. The most prolific oil sands are those immediately above this diatomaceous shale, and in general the sands become less productive the farther they are removed from it. Moreover, the seeps of oil that occur farther south, along Reef Ridge, bear a similar relation to the diatomaceous Oligocene (?) shale.

The absence of outcrops of the Oligocene (?) shale and the Tejon formation (Eocene) in the area south of Curry Mountain is therefore of prime importance in considering the possible occurrence of oil in this part of the region. The southernmost exposure of this shale and of the Tejon formation north of Alcalde Canyon is near the San Joaquin Valley coal mine 3 miles due west of Coalinga. From that place to Sulphur Canyon, 10 miles almost due south of Coalinga and about 3 miles east of the southeast corner of the area mapped, the Oligocene (?) shale and the Tejon are covered by younger formations. The western boundary of the shale and the Tejon beneath the mantle of younger formations is of course not known, but as they do not outcrop in the western end of Reef Ridge it seems probable that the Eocene-Cretaceous contact has a general northwest-southeast trend parallel to the structure lines in the outer foothills south of Coalinga, and that the Oligocene (?) shale and the Tejon do not extend far, if at all, west of the axis of the Jacalitos syncline. The Vaqueros and Santa Margarita (?) formations likewise are covered by the later Tertiary strata, but as they are exposed along the south side of upper Jacalitos Creek it is evident that both of these formations extend somewhat farther west than the Tejon and the Oligocene (?) shale. An attempt has been made in the diagrammatic section (fig. 5) to show the probable attitude and relationship of the Tertiary formations in the area southeast of Curry Mountain. The Oligocene (?) shale and Tejon formation are shown extending a short distance west of the axis of the Jacalitos syncline, where they are overlapped by the unconformably overlying Vaqueros formation. From this point they are continuous eastward and probably underlie much of the broad Kettleman Plain. It is believed that petroleum has originated here, as it has in the Coalinga field to the north, in the diatomaceous Oligocene (?) shale that overlies the Eocene Tejon formation and has migrated into the overlying Vaqueros to places where the structure is favorable for its retention. It was pointed out in the Coalinga report¹ that the Jacalitos anti-

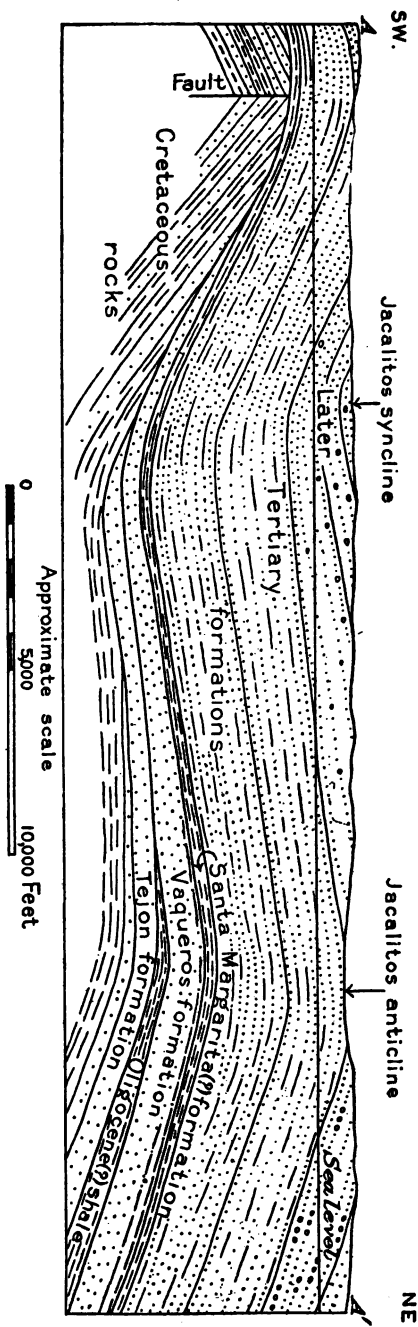
¹ U. S. Geol. Survey Bull. 398, pp. 238, 239, 1910.

cline is a favorable place for the collection of such oil. Since that report was written wells drilled along this fold have obtained some light-gravity oil, apparently from the Vaqueros formation, at depths of 3,700 to 4,400 feet. The question now arises whether or not sufficient oil is present to saturate not only the sands along the Jacalitos anticline but also those on the west side of the Jacalitos syncline in a manner analogous to the occurrence of oil in both the Coalinga anticline and syncline.

The general conditions in this area south of Curry Mountain are similar to those in sec. 2, T. 21 S., R. 14 E., a mile or so west of the Westside Coalinga field, where the Vaqueros formation rests directly upon Cretaceous beds. Wells drilled in this northern region obtain oil at a shallow depth from beds in the lower part of the Vaqueros. The conditions in sec. 2 are shown diagrammatically in figure 6.

The oil obtained in the wells in and near sec. 2 probably had its origin largely in the Oligocene (?) shale, migrated into the Vaqueros and thence to the west up the dip, to accumulate finally in the area where the Vaqueros is but slightly tilted. Although there is thus a general similarity between the structure of the area south of Curry Mountain and that of the area above mentioned, north of Alcalde

FIGURE 5.—Hypothetical cross section in the Jacalitos Hills, Cal., from a point near the south end of Curry Mountain to the Jacalitos anticline.



Canyon, it appears rather unlikely that oil has migrated in quantity west of the axis of the Jacalitos syncline to collect in the irregu-

larly folded rocks south of Curry Mountain. The Oligocene (?) shale evidently lies much farther east in this area than in the area in sec. 2 north of Alcalde Canyon, and the Jacalitos anticline, along which oil rising from beneath the valley to the east would probably tend to collect, is interposed between the area of low dip near Curry Mountain and most or possibly all of this shale. More direct evidence on this point is the fact that the outcrops of the sands in the lower part of the later Miocene formations, where they are in contact with the Cretaceous on the southeast slope of Curry Mountain, show no trace of oil, whereas the outcrops of the Miocene sands from which the wells in sec. 2, T. 21 S., R. 14 E., derive oil do show such traces. The wells that have been drilled along the Jacalitos anticline,

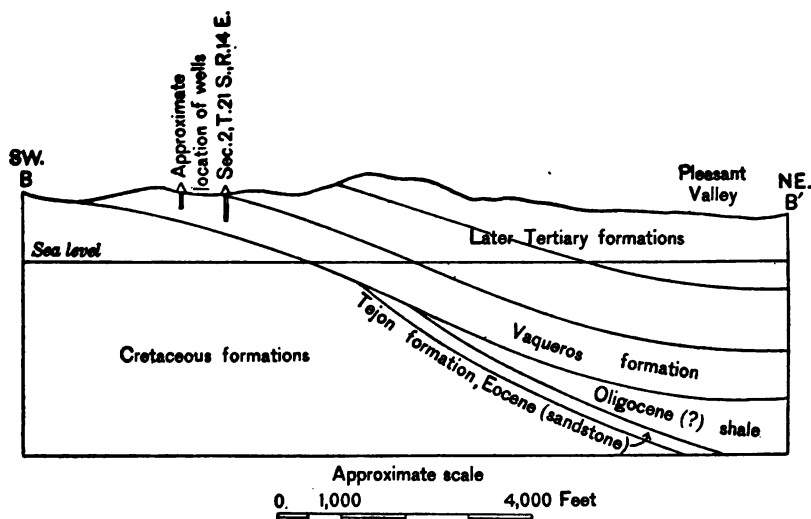


FIGURE 6.—Hypothetical cross section in the western part of the Coalinga oil field, Cal. Adapted from U. S. Geol. Survey Bull. 398, fig. 8, p. 191, 1910.

although they prove the presence of oil, have not yet shown that it occurs in great quantities. Unless the sands along the anticline are saturated with oil it is improbable that they will contain it farther west. Thus any prospecting in the area south of Curry Mountain should await further work along the anticline to the east.

Two formations other than the Oligocene (?) shale might be regarded as possible original sources of oil in the Jacalitos Hills—one the shale that occurs at the top of the Cretaceous in the north end of the Coalinga field and the other the shale of the Santa Margarita (?) formation. It is unlikely, however, that much if any oil which may have formed in either of these shales has collected in the Tertiary beds at the south end of Curry Mountain. The nearest exposures of the Cretaceous shale are in the north end of the Coalinga

field. This shale is not exposed south of Coalinga, and in all probability if it underlies the Jacalitos Hills at all it is much farther east than the Oligocene (?) shale and is therefore a much less likely source than that formation. As for the shale of the Santa Margarita (?) it should be noted that where it is exposed on Jacalitos Creek, at the north end of Reef Ridge, that formation is not more than 300 or 400 feet thick. Moreover, this formation evidently decreases in thickness toward the north, beneath the cover of the younger formations, and it is not exposed in the steeply tilted monocline of late Tertiary formations in the foothills north of Coalinga.

WELLS DRILLED FOR OIL.

Wells drilled along the Jacalitos anticline by the Bohemian Oil Co. and the Hub Oil Co. are said to have found oil sands at depths of about 3,700 and 4,300 feet, respectively. Farther southeast along the same fold the well of the Azores Oil Co. is said to have obtained oil at 3,500 feet. In the Jacalitos syncline to the west several wells have been drilled, but so far as the writers are aware none of them penetrated the strata of the later Tertiary formation and reached the horizons at which oil sands, if they exist in the region, might be expected to occur.

About 13 or 14 years ago three wells were drilled along the upper part of Jacalitos Creek. Two were put down by the Whale Oil Co. in the SE. $\frac{1}{4}$ sec. 4, T. 22 S., R. 14 E., one to a depth of 650, the other 600 feet. Salt water was obtained in the deeper well. Near the south line of sec. 32, T. 21 S., R. 14 E., the Venus Oil Co. drilled a well about 1,500 feet deep without obtaining oil. These three wells could hardly have been drilled in more disadvantageous places, for the Tertiary beds are steeply tilted and faulted, offering no favorable structure for the concentration of oil should it have occurred disseminated through the strata.

WALTHAM AND PRIEST VALLEYS.

The Tertiary formations in Waltham and Priest valleys lie in a structural depression that trends diagonally across the Diablo Range. The structure, though in general synclinal, is complicated, especially on the southwest, by numerous small folds and faults that have in-folded or dropped blocks of the Tertiary beds into the Franciscan. This structure is not specially favorable for collecting any petroleum that may have occurred in small quantities throughout the rocks, nor are there here any large areas underlain by diatomaceous shale from which oil might be derived. The diatomaceous shale of the Santa Margarita (?) formation has at best relatively small distribution, even though it underlie most of the region where the later Miocene formations appear at the surface. The tremendously thick section

of dark carbonaceous shale that forms the lower part of the Cretaceous on the north side of Waltham Valley might be regarded as an original source of petroleum, but its high and regular dips afford no favorable structure for the accumulation of oil, even if it were originally present.

Indications of oil have been reported near the northwest corner of sec. 28, T. 20 S., R. 13 E., along the fault that extends northwest-southeast through the hills on the north side of Waltham Valley, about a mile west of Fresno Hot Springs. The writers were unable to confirm this report but are inclined to credit it. Such oil may have risen either from the dark carbonaceous shale of the Cretaceous or from the diatomaceous shale of the Santa Margarita (?), which supposedly lies beneath the later Tertiary strata north of Waltham Creek. Of the two possibilities the first seems the more probable.

Wells have been drilled for oil at two places on the north side of Waltham Valley near the reported seep. Just south of the southeast corner of sec. 20, T. 20 S., R. 13 E., five wells were put down within a few hundred feet of one another 9 or 10 years ago by the Echo Oil Co. The deepest well, No. 2, is said to have been drilled to a depth of 1,400 feet. Two of the wells are said to have obtained small quantities of gas and oil, and it is commonly reported that as much as 5 or 6 gallons of light-gravity oil has been bailed out at a time. About a mile to the southeast, near the center of sec. 33, T. 20 S., R. 13 E., is the Warthan Oil Co.'s well. Drilling has been carried on here at various times since 1909 but was suspended in September, 1913, for lack of funds. This well and those of the Echo Oil Co. are close to a large fault, along which the strata are steeply tilted and much fractured. If oil did occur in the rocks, it probably would have tended to migrate from the beds that lay relatively close to the fault into the crushed zone, but the position and attitude of the more distant rocks make it improbable that oil from any very great thickness of beds would have migrated in this manner. Also, the beds along the fault are so steeply tilted and so broken that they offer a ready avenue of escape to the surface for any oil which might be contained in them.

BITTERWATER AND PEACHTREE VALLEYS AND FOOTHILLS TO THE WEST.

GEOLOGY.

West of the San Andreas fault zone the beds mapped as upper Miocene rest directly upon the eroded surface of the granite. In the area shown on the map these beds have a maximum thickness of about 3,300 feet and comprise two formations, of which the lower, made up of sand, clay, gravel, and diatomaceous shale and filled with marine fossils, is believed to be the equivalent of the Santa Margarita formation, and the upper, composed of material that was

probably laid down in lakes or subaerially, is the equivalent of the Tulare formation. West of Peachtree Valley the upper of the two formations is relatively unimportant, appearing only in isolated areas along the crests of the ridges as a cap less than 200 feet thick. The beds that are comprised in the formation that is considered the equivalent of the Santa Margarita are variable in character, ranging from coarse conglomerate to fine diatomaceous shale, but for the most part are fine grained. Near Lonoak and in Bitterwater Valley the lower $1,000 \pm$ feet is composed of diatomaceous shale, which forms prominent white outcrops that are especially noticeable about 2 miles northwest of Lonoak post office. Shale of this type forms the lower part of the Tertiary along the west side of Bitterwater Valley, in the north end of Mustang Ridge, in small areas near the east corner of the Peachtree ranch, and in much of the Topo ranch northwest of the area mapped. In many other parts of the region, however, sandy or even gravelly beds, such as those exposed near the asphalt quarry west of Lonoak, rest upon the granite. Practically no diatomaceous shale appears resting upon the granite near its exposures in small areas 4 miles southwest of Lonoak. The variability in the lithology of the lower part of the Tertiary is well shown along the north side of San Lorenzo Creek west of the granite that is exposed at the edge of the area mapped. Possible explanations of the variability in the thickness of the diatomaceous shale appear to be (1) that the Tertiary beds were laid down upon a very uneven surface of granite and that in parts of the region the lower beds were not deposited; (2) that the shale actually grades laterally into coarser materials; (3) that the diatomaceous shale is older than the clay and shale and is separated from them by an unconformity. The most probable explanation seems to be that the variability in the thickness of the shale is due both to lateral variation in character and to the uneven surface upon which it rests. Sandy beds intercalated with the diatomaceous shale contain fossils apparently of precisely the same type as those in the overlying sandy beds, and it seems improbable that any considerable time intervened between the deposition of the two divisions. The presence or absence of the diatomaceous shale is of considerable importance, for the seeps of oil appear only in those areas where it has considerable thickness.

The Tertiary strata that cover the granite have not been deformed to any very marked degree west of the San Andreas fault zone. West of Peachtree Valley nearly to the edge of the area mapped this cover may be thought of as a sheet, very slightly wrinkled along irregular lines and in general dipping slightly toward the northeast. Farther west the dip changes; along the edge of Salinas Valley it

is in general toward the west, carrying the beds beneath the valley. Between Peachtree Valley and the San Andreas fault zone is a shallow syncline, which the writers have termed the Peachtree syncline. This fold starts near the center of the Peachtree ranch and continues northwest through the Topo ranch, beyond the area mapped. The east flank of this syncline is terminated by the San Andreas fault zone, along which the beds of diatomaceous shale in the lower part of the later Miocene formations are so tilted that they are nearly vertical. North of Lonoak the southwest flank of the syncline merges with the area of low irregular dips along the foothills east of the Salinas Valley, but along the Peachtree Valley it is apparently terminated by a fault. It is in this synclinal basin that most of the drilling for oil has been done. Along the San Andreas fault a zone varying from three-quarters to 1 mile in width is traversed by innumerable faults and the rocks are greatly shattered. In this zone rocks of the Franciscan and later formations are intermingled in irregular masses, and along the west side steeply tilted beds of diatomaceous shale occur. Through this zone of fracture oil contained in the rocks has found an easy passage to the surface. Several wells have been drilled along it, but none of them have found any considerable reservoir of oil.

SURFACE INDICATIONS OF PETROLEUM.

In several places in Bitterwater and Peachtree valleys oil impregnates the surficial sandy beds that lie in the San Andreas fault zone or that rest upon the granite. The largest of these outcrops occurs at the Mylar asphalt quarry, in secs. 14 and 15, T. 19 S., R. 9 E., about 2 miles west of Lonoak. The basal 25 to 50 feet of the later Miocene here is a coarse arkosic sand or grit that was evidently derived from the granite upon which it rests. The outcrops of this sand for a distance of about one-half mile are impregnated with tarry oil or asphalt, the amount contained varying from place to place. Where the outcrops are weathered and unbroken the sand is light brown and friable, but in the newer faces of the quarry the sand is plastic from the amount of tar it contains, and in one place thick oil slowly oozes out along its contact with the underlying granite. The oil sand or asphalt is quarried from time to time and used in repairing the roads about King City. Most of the sand is of medium coarse grain, and the material is used directly upon the roads without the addition of more sand.

Oil-saturated sands outcrop at two places near the southeast corner of the Peachtree ranch, in what corresponds to the SE. $\frac{1}{4}$ sec. 22 and the SW. $\frac{1}{4}$ sec. 25, T. 20 S., R. 11 E. At the first-named locality a massive sandstone that stands almost vertical occurs on the west side of an area of much contorted diatomaceous shale. The relationship of the sandstone and shale is not entirely clear, as the rocks are con-

siderably faulted, but the sandstone is believed to be stratigraphically above most or possibly all of the shale. The sandstone is impregnated with heavy oil, which slowly seeps out in the bottom of one of the steep arroyos. About $1\frac{1}{2}$ miles southeast of this seep a sandstone 50 to 60 feet thick, bedded with the diatomaceous shale that occurs near the base of the Tertiary, is impregnated with oil. This bed appears to be a sandy lens in the upper part of the diatomaceous shale. It lies at the western edge of the San Andreas fault zone, is much fractured, and is truncated on the east by a fault that brings it into contact with the clay in the Tulare formation.

Where the San Andreas fault crosses Alvarez Creek, in sec. 32, T. 18 S., R. 10 E., an outcrop of much fractured coarse arkosic sandstone in the Tulare formation is stained by petroleum, and wells less than 100 feet deep sunk here have yielded a little light-gravity oil.

About 13 miles due north of King City, approximately in sec. 29, T. 17 S., R. 8 E., at the Matthews asphalt quarry, a bituminous sandstone outcrop lies, like that at the Mylar quarry near Lonoak, between outcrops of granite and of diatomaceous shale. This sandstone may underlie the diatomaceous shale, as was suggested by Eldridge,¹ but as the oil sand is limited to the small gulch tributary to Chalone Creek and contains besides granitic material an appreciable number of diatomaceous shale fragments, the writers suggest that it is probably a stream terrace deposit impregnated with and cemented by thick tarry oil that seeped out of the lower part of the diatomaceous shale. The beds of sand and gravel impregnated with oil are of very uneven grain and on the whole are much coarser than those at the Mylar quarry.

WELLS DRILLED FOR OIL.

The following wells have been drilled for oil in and near Bitterwater and Peachtree valleys:

- Nonpareil No. 1, sec. 32, T. 18 S., R. 10 E.
- Nonpareil No. 2, sec. 32, T. 18 S., R. 10 E.
- Nonpareil No. 3, sec. 32, T. 18 S., R. 10 E.
- Lonoak No. 1, sec. 7, T. 19 S., R. 10 E.
- Lonoak No. 2, sec. 31, T. 18 S., R. 10 E.
- Alvarez No. 1, sec. 33, T. 18 S., R. 10 E.
- Le Franc No. 1 (Standard Oil Co.), Topo ranch, in what corresponds to sec. 33, T. 17 S., R. 9 E.
- Tompkins No. 1 (Standard Oil Co.), sec. 19, T. 19 S., R. 10 E.
- Tompkins No. 2 (Standard Oil Co.), sec. 19, T. 19 S., R. 10 E.
- Landrum No. 1 (Standard Oil Co.), sec. 28, T. 19 S., R. 10 E.
- Doheny well, sec. 14 or 15, T. 19 S., R. 9 E.
- Miller No. 1 (Union Oil Co.), Peachtree ranch, in what corresponds to sec. 24, T. 20 S., R. 10 E.
- Salinas No. 1, sec. 9, T. 19 S., R. 10 E.

¹ Eldridge, G. H., The asphalt and bituminous rock deposits of the United States: U. S. Geol. Survey Twenty-second Ann. Rept., pt. 1, pp. 409-410, 1901.

The Nonpareil wells were drilled about 13 years ago near the seep where the San Andreas fault crosses Alvarez Creek. Previous to the drilling of the main wells, two wells were drilled by hand, the deeper of which is said to have obtained light-gravity oil at 60 to 70 feet. At the time of the writers' visit it had caved below the 55-foot depth and was dry of oil, although containing considerable gas. Of the three larger wells, No. 1 is said to have reached a depth of 1,038 feet without obtaining more than a trace of oil. Well No. 2 was drilled 653 feet and obtained oil between 400 and 520 feet. Oil now stands in the hole, but the well has never produced. Well No. 3 reached a depth of 1,300 feet, having been drilled through "a great mixture of rocks," but obtained no oil.

Lonoak well No. 1 was sunk about 2,700 feet and is said to have reached granite at that depth without having encountered a trace of oil. Well No. 2 reached a depth of 3,009 feet, getting a little tarry oil at 600, 800, and 1,800 feet. A few barrels of oil is said to have been pumped.

The Salinas well is said to have been drilled to 450 feet and at that depth to have found a little very heavy oil like that in Lonoak well No. 2.

The Doheny well, near the southwest corner of sec. 14, T. 19 S., R. 9 E., starts about 750 feet south of the outcrop of the oil sand at the Mylar asphalt quarry. It is said to have reached the granite at 900 feet without having found oil. The lack of success of this well is striking and shows the local character of the oil sand that is quarried as asphalt.

The Alvarez well was started a few hundred feet south of the old Nonpareil wells and drilled to a depth of 900 feet but obtained no oil.

The Le Franc well of the Standard Oil Co., at the head of Bitterwater Valley, within a few hundred feet of the San Andreas fault line, was drilled to a depth of more than 2,000 feet. It is said to have penetrated considerable oil sand but produced no oil. The fractured condition of the beds here prohibits an estimate of the stratigraphic position of the oil sands penetrated.

The two Tompkins wells and the Landrum well of the same company were drilled in Peachtree Valley and are said to have reached a "hard gray sand" without finding more than a trace of oil. It may be that the "gray sand" is an arkosic sand derived from the granite and is similar to that at the asphalt quarry west of Lonoak, but the writers believe that it is more probably granite.

The Miller well of the Union Oil Co., near the west edge of the Peachtree ranch, along the road from Peachtree Valley to Salinas Valley was drilled to a depth between 2,500 and 2,600 feet, but no oil was found.

ECONOMIC POSSIBILITIES.

Along the San Andreas fault the beds are broken and all the formations are so intermingled in small irregular masses as to form a structure exceptionally unfavorable for the accumulation and retention of petroleum. It is true that oil contained in the solid rocks in the immediate vicinity would probably work its way into the crushed zone, but it is difficult to believe that it would be held there in quantity and would not work its way to the surface. Thus, although seeps of oil occur along this zone, and although wells such as Lonoak well No. 2 and the Salinas well have obtained small quantities of oil, the presence of oil beneath the surface in sufficient amount to make drilling profitable seems very unlikely. Also, the experience in other California fields shows that oil contained in rocks so badly fractured as these is of variable character and that much of it is of heavy gravity. Thus the oil found in the Lonoak and Salinas wells is probably typical of the oil that does occur, despite the fact that small quantities of light-gravity oil have been found in shallow wells on Alvarez Creek.

Of the 3,000 feet or more of Miocene beds which are infolded in the Peachtree syncline near Lonoak the lower 1,000 feet or so is largely diatomaceous shale. This shale is continuous southward but seems to become more sandy in that direction. That the beds associated with the shale contain some oil is shown by the outcropping oil sands in the southeast corner of the Peachtree ranch and by the results obtained in the wells near the mouth of Lewis Creek. However, the writers believe it doubtful that oil has accumulated here in any considerable amount. The syncline is structurally isolated, being bounded sharply on the east by the San Andreas fault zone and on the southwest by the granite and probably by a fault extending along Peachtree Valley. Thus it seems improbable that oil could have collected in this basin from the rocks underlying any very extensive area. Any oil which might have been formed in the beds beneath Salinas Valley would probably not travel eastward beyond the area west of Peachtree Valley, in which the Tertiary beds are wrinkled irregularly. Moreover, except in a small area near the mouth of Lewis Creek, where the beds are slightly domed, the general synclinal structure is not favorable for the collection of petroleum. Even the doming cited is really so slight and lies so close to the badly fractured San Andreas fault zone that it is improbable that oil has collected in it. The wells which have been drilled here have pretty thoroughly tested the area, and it is believed that further drilling, even along the small fold mentioned above, will fail to disclose any extensive accumulations of oil.

The low foothills between the Peachtree and Salinas valleys present many of the features exhibited by the large productive fields in California, and in this area alone, of all the region studied, does there appear to be a possibility of obtaining oil. The factors supporting the theory that oil may have accumulated here in considerable amounts may be listed as follows: (1) Some oil is undoubtedly present, as is shown by the outcropping oil sand at the asphalt quarry near Lonoak and at the south end of the Peachtree ranch; (2) diatomaceous shale, which is regarded as the ultimate source of the oil in this part of the State, is bedded with, overlain by, and underlain by porous sandstone, which, although mostly of rather fine grain, would serve as an excellent reservoir for oil; (3) the sandy beds are somewhat lenticular and are intercalated with clay or shale, thus probably furnishing local reservoirs of porous material more or less completely inclosed in impervious walls; (4) the beds are tilted slightly and irregularly, locally forming small, low structural domes; (5) to the west is the broad synclinal Salinas Valley, under which lies part at least of the thick mass of diatomaceous shale that outcrops along the Santa Lucia Range on the west side of the valley. Thus there is an area of considerable size from which oil might have risen to collect in the slightly folded rocks.

Although the broader features of the stratigraphy and structure appear to favor the hypothesis that oil has accumulated in the foothills west of Peachtree Valley, two important questions remain to be answered, and to neither of them does the answer seem favorable, so far as may be judged from the areal geology. They are (1) whether the oil, though undoubtedly present, was formed in quantities in any way comparable with those found in the southern end of the San Joaquin Valley; and (2) whether, if any considerable quantity of oil was formed beneath the valley, it would have collected in the beds in the foothills on the east side in reservoirs of sufficient size to be commercially valuable.

It seems probable that the first question must receive a negative answer. Seeps of oil and dry oil sands occur not only in the region described but also to the southeast, in the Parkfield region, and at intervals for several miles on the west side of the valley. In other words, the outcrops of the Tertiary rocks on both sides of the basin show evidence of petroleum, and it is reasonable to suppose that the beds in the center of the basin, now covered by alluvium, also contain or at one time contained it. The basin occupied by sedimentary rocks here is, however, of much smaller area than that at the southern end of the San Joaquin Valley; the diatomaceous shale in it is far thinner than that in the Temblor Range and along the east side of the Salinas Valley is somewhat irregularly developed, owing, in part, to its having been laid down upon a very irregular

surface of granite and probably also in part to the fact that it is replaced in some areas by sandy beds. This irregularity is well shown along San Lorenzo Creek. Near Lonoak the lower 1,000 feet or so of the later Miocene is fairly pure diatomaceous shale, but less than 2 miles downstream sand and sandy clay, in lithologic character precisely like the beds overlying the diatomaceous shale near Lonoak, rest directly upon the granite. Also, near the small granite exposures some 4 miles southwest of Lonoak the sedimentary beds are entirely sand and sandy clay. Thus if the diatomaceous shale is regarded as the ultimate source of the oil it is unreasonable to suppose that so great quantities of oil were formed here as were formed in the southern end of the San Joaquin Valley.

The oil seeps in the region studied are very closely associated with the diatomaceous shale, and practically none is known in an area in which the shale has not considerable development. It is not unreasonable to suppose that beneath the alluvial filling in Salinas Valley the diatomaceous shale has as irregular a development as it has where exposed in the area studied. If such is the case, unless there is some special cause for its further migration, any oil which may have originated in the shale would probably not move farther than the sandy beds interstratified with or immediately adjacent to the shale. Thus the tendency would be for the formation of a number of small local concentrations.

So far as the effect of the structure upon a possible accumulation of oil is concerned, the most notable feature in the foothills between Peachtree and Salinas valleys is the lack of any well-defined fold at all comparable with those which, south of Coalinga, border the San Joaquin Valley on the west and along which lie the productive oil fields. Instead of being strongly folded the Tertiary beds along the east side of Salinas Valley are but slightly tilted, in much of the area less than 2° . The importance of this difference in structure can hardly be overestimated in considering the possibility of oil having accumulated in considerable quantity.

Along the edge of Salinas Valley the dip is in general southwest, but near the border of the area mapped it is northeast. The change does not take place along a line, but rather along an ill-defined belt several miles in width, or it perhaps may best be described as being marked by a number of short irregular domes of which three appear in the area mapped. One occurs near the asphalt quarry west of Lonoak, where the later Miocene beds dip 2° to 7° away from the granite. The second occurs west of the Peachtree ranch, where a line trending northwest-southeast through secs. 16 and 22, T. 20 S., R. 10 E., separates the beds that dip about $2\frac{1}{2}^{\circ}$ SW. from those that dip approximately as much northeast. The third occurs just northwest of the isolated outcrop of granite some 4 miles southwest of

Lonoak. These uplifts are so gentle that their axes can not well be designated by a definite line, but their position is indicated by the dips given on the map.

In San Joaquin Valley the sandy beds along the anticlines have served as reservoirs for oil that is believed to have once been contained in beds that extended over large areas. Much of the oil probably originated beneath San Joaquin Valley, worked its way up the rise, and accumulated in the upper parts of the folds. On the east side of Salinas Valley, however, no such folds dominate the structure and there appears to be no reason why oil that may occur disseminated through the rocks over a wide area should accumulate in considerable amounts in a single small area. On the contrary, oil which may have originated beneath the valley would probably tend to remain in the upper parts of the numerous low, faint domes or wrinkles. Moreover, the diatomaceous shale is much thinner along Salinas Valley than it is along the western border of San Joaquin Valley; hence it is even more necessary in Salinas than in San Joaquin Valley that a structural feature which favors the accumulation of oil should have tributary to it a large area from which oil may be drained.

In conclusion it may be said that the irregular structure, the irregular distribution of the diatomaceous shale, and the lenticular character of the sandy beds all seem to indicate not that oil has accumulated in any considerable quantity in few localities but rather that it has accumulated in small amounts at a number of places in the upper parts of low folds or domes. It is not at all unlikely that wells drilled along the axes of the low anticlinal folds that lie between Salinas River and Peachtree Valley will find oil. It is to be expected, however, that the area that may prove productive is very irregular in outline, and that the amount of oil in the producing wells will be small. Thus for many years to come the cost of prospecting this region with the drill will probably be much greater than the value of the oil that may be obtained.

So far no well has adequately tested the area west of the Peachtree Valley. The well most advantageously placed is the Miller well of the Union Oil Co., which was drilled near the southwest side of the Peachtree ranch, about a mile east of the line of change in dip, in secs. 22 and 16. Although the test would have been more satisfactory had the well been located farther west, still the failure to obtain oil in it goes far to prove that any oil sands which may occur here are of small extent. Also, the outcrops of granite some 4 miles southwest of Lonoak are significant, for although there is here a slight fold or dome comparable with that near Lonoak, yet the beds, unlike the Tertiary sands at Lonoak, show not the slightest trace of oil.

OUTLYING DISTRICTS.

The following brief notes regarding the geology and possible occurrence of oil in the Topo ranch, which lies beyond the boundary of the area shown on the map, in the upper part of the valley of San Benito River, are based on hurried visits made during the course of the work.

TOPO RANCH.

The Peachtree syncline continues as a broad, shallow fold north-westward beyond the area shown on the map, passing through the Topo ranch. On the east the syncline is terminated by the San Andreas fault zone and on the west by the granite which here appears at the surface in the Gabilan Range. Along the west side of the syncline the lower part of the Tertiary section consists of chalky white diatomaceous shale having a maximum thickness of not more than 1,000 feet. Upon the shale rest a few hundred feet of sandy beds, which constitute both the Santa Margarita and the Tulare formations. The beds for half a mile on either side of the axis of this syncline dip at angles of less than 5° and on the west flank of the fold at angles of less than 10° as far as the granite hills. The Matthews asphalt quarry (see p. 147) is on the west flank of this syncline at the contact between the granite and overlying Tertiary beds.

Five wells have been drilled by the Standard Oil Co. in this syncline on or south of the Topo ranch. Some of them were drilled through the Tertiary beds to the underlying granite, but none found more than a trace of oil or gas. Their names and location are given below:

Dunne No. 1, Topo ranch, west of Dunne ranch house.

Dunne No. 2, Topo ranch.

Brown No. 1, sec. 15, T. 17 S., R. 8 E.

Stone No. 1, sec. 27, T. 17 S., R. 8 E.

Leonard No. 1, sec. 28, T. 17 S., R. 8 E.

The Leonard well, drilled about one-third of a mile east of the Matthews asphalt quarry, started in the diatomaceous shale and struck heavy oil and tar not far above the granite.

This synclinal basin in and north of the Topo ranch presents few features which would make it appear probable that oil has collected in it in considerable quantity. It is isolated, being bounded sharply on the northeast by the San Andreas fault zone and on the west by the granite of the Gabilan Range, and is thus almost cut off from the Tertiary rocks in Salinas Valley. These conditions make it difficult to believe that the syncline has acted as a catchment basin for oil drawn from great stretches of rocks in the surrounding territory. Moreover, the synclinal structure is not especially favorable to the concentration of oil, as any oil that did exist in this rock would

be forced up the rise and would appear at the surface, as it has at the Matthews asphalt quarry. Finally the wells that have already been drilled have pretty thoroughly tested the area.

SAN BENITO RIVER VALLEY.

East of San Benito River, near the southwest corner of T. 17 S., R. 10 E., later Miocene beds, approximately the equivalent of the Etchegoin formation of the Coalinga region, dip rather regularly 20° - 30° SW. About a mile northeast of the area mapped these beds are broken by a fault which is approximately parallel to the San Andreas fault. A short distance northeast of this fault Cretaceous, Eocene (?), and Franciscan (Jurassic?) rocks appear. The upper part of the Miocene beds is mainly massive arkosic sandstone filled with marine fossils. Beneath these beds are alternating beds of reddish and greenish clay and gravel, much like the beds that appear along the axis of the Vallecitos syncline, about 10 miles away on the opposite side of the Diablo Range, and presumably of upper Miocene age.

There seems to be no reasonable chance of obtaining oil in this part of the San Benito River valley. So far as known no seeps of petroleum occur here, although the rocks are broken and are in places much shattered by faults, so that oil certainly would have had abundant opportunity to reach the surface if it ever had been present. Also, so far as known, no masses of sedimentary rocks that contain any considerable amounts of organic material, such as diatomaceous or carbonaceous shale, occur in this region. Finally, the structure is not especially favorable to the accumulation of oil.

It has been said that the value of this region as oil-producing territory is shown by the fact that it lies midway between Bitterwater Valley and the Vallecitos, in both of which seeps of oil occur. This can hardly be considered a valid argument, as the area is separated from the Bitterwater region by the San Andreas fault and from the Vallecitos by a great mass of Cretaceous and Franciscan (Jurassic?) rocks, which lie stratigraphically below the oil-bearing rocks.

The McMurtry-Hoeppner well, near the west line of sec. 32, T. 17 S., R. 10 E., is on James Creek, a tributary of San Benito River from the northeast. The well starts in the fossiliferous late Miocene beds and, when visited in November, 1913, had been drilled to a depth of 1,462 feet and had apparently reached the clay and gravel that form the lower part of the upper Miocene. No trace of oil had been obtained.

COAL.**OCCURRENCE AND AGE.**

Coal occurs in the Tertiary beds in the Priest Valley syncline and at several places in the hills on the south side of Waltham Valley. About 4 miles south of the summit of Smith Mountain is the Stone Canyon mine, at which coal has been mined at irregular intervals for many years. The coal beds within the boundaries of the area shown on the map have been prospected at a number of places, but when visited in the later part of 1913 none of the prospects remaining open furnished a good section of the beds and no fresh samples of the coal were obtained. Although no attempt was made to study the coal beds in detail, the following facts, which were brought out in the course of the work, regarding the age of the different carbonaceous beds and their general distribution are believed to be of sufficient importance to record. The points of chief interest are that coal occurs at three horizons in this part of the Diablo Range—in the Eocene, the lower Miocene, and the upper Miocene; that the coal in Priest Valley is not, as is commonly thought, the same as that in Stone Canyon but is younger and apparently of much poorer quality; that the coal occurs in small isolated structural basins and not, as has been reported, in a continuous bed or succession of beds extending from Stone Canyon northwestward to the valley of San Benito River.

EOCENE COAL.

Coal occurs in Eocene beds exposed west of Coalinga and was mined there some 20 years ago. In 1893 approximately 400 tons were shipped, principally to Fresno, from the San Joaquin Valley and California mines.¹ The enterprise, however, did not prove profitable, and mining was discontinued even before oil was discovered in the region in quantity.

The coal occurs in the white quartzose sandstone of the Tejon formation in thin, discontinuous beds, most of them less than a foot thick, although it is said that the "big vein" in the old mines is about $4\frac{1}{2}$ feet thick.

Coal occurs in the Eocene sandstone (Tejon formation) at many places along the foothills on the east side of the Diablo Range northwestward from Coalinga, but principally on the south side of the Vallecitos in T. 17 S., Rs. 11 and 12 E. On the west side of the summit of the Diablo Range in secs. 20 and 21, T. 17 S., R. 10 E., 2 miles north of the area shown on the map, is the Trafton mine, which

¹ California State Mining Bureau Twelfth Rept. California State Mineralogist, pp. 50-54, 1894.

was described briefly by Campbell.¹ The coal occurs in sandstone that, as nearly as could be determined in the brief time spent in the region, occupies about the same stratigraphic position as the coal-bearing beds in the Vallecitos, some 6 miles to the east, and, although no diagnostic fossils were found in the coal-bearing beds, the coal at the Trafton mine is probably of Eocene age.

LOWER MIOCENE COAL.

The coal at Stone Canyon, in the center of T. 22 S., R. 13 E., has been described briefly by Arnold² and Campbell.³ It occurs in the lower part of the Vaqueros formation (lower Miocene) close to the contact with the Cretaceous rocks and the Franciscan formation (Jurassic?), upon which the Vaqueros rests unconformably. On the opposite (northeast) side of the Diablo Range the lower part of the Vaqueros is exposed in the area discussed in the present report on both flanks of the syncline that trends northwest on the north side of Smith Mountain. The lower beds are best exposed on the south flank of the syncline from the head of Jacalitos Creek, in sec. 35, T. 21 S., R. 13 E., northwestward through secs. 34, 33, and 28, and on the north flank of the fold in the NW. $\frac{1}{4}$ sec. 21 of the same township just west of the trail that leads from Waltham Valley to Bourdieu Valley. In both places the beds are rather steeply tilted, dipping 40°-75°. These dips are, however, restricted to a relatively narrow belt, and in much of the intervening area, closer to the axis of the syncline, the Vaqueros is tilted less than 30°.

The coal-bearing portion of the formation lies below the massive calcareous sandstone which outcrops along the crest of the ridge and which forms the top of Smith Mountain and Smith Pinnacles. It varies greatly in thickness and in character and is evidently a near-shore deposit that was laid down upon a very uneven surface of Franciscan, Knoxville, and Chico rocks. This part of the Vaqueros weathers easily and, occurring as it does beneath a massive cliff-forming sandstone, furnishes few good exposures. At the head of Jacalitos Creek, in the SW. $\frac{1}{4}$ sec. 35, T. 21 S., R. 13 E., the beds beneath the massive calcareous sandstone have a thickness of at least 200 feet. The upper 100 to 150 feet is composed of beds of greenish or bluish conglomerate formed largely of fragments of Franciscan rocks, beneath which is 75 to 100 feet of carbonaceous and perhaps in part diatomaceous shale. The outcrop of this shale

¹ Campbell, M. R., Coal in San Benito County, Cal.: U. S. Geol. Survey Bull. 431, p. 243, 1911.

² Arnold, Ralph, Coal in the Mount Diablo Range, Monterey County, Cal.: U. S. Geol. Survey Bull. 285, pp. 223-225, 1906.

³ Campbell, M. R., Coal of Stone Canyon, Monterey County, Cal.: U. S. Geol. Survey Bull. 316, pp. 435-438, 1907.

is apparently terminated on the south by a fault that has brought the shale into contact with sandy shale and somewhat concretionary sandstone whose exact stratigraphic position is not known. The carbonaceous shale is, however, not far above the base of the Vaqueros. On the north side of this syncline, in the NW. $\frac{1}{4}$ sec. 21, T. 21 S., R. 13 E., the following section is exposed. The thicknesses given are estimates but are probably accurate within 10 per cent.

Incomplete section of carbonaceous beds in lower part of Vaqueros formation in NW. $\frac{1}{4}$ sec. 21, T. 21 S., R. 13 E.

	Feet.
A. Sandstone, massive, somewhat calcareous; basal bed filled with large oyster shells. Probably the lower part of the sandstone that forms Smith Pinnacles.	
B. Sandstone, less massive than bed A, light gray, weathering to yellow-brown.....	10
C. Sandstone, somewhat carbonaceous, rather shaly, weathering red-brown. Bed 1 foot thick 6 feet above base is filled with large oyster shells.....	16
D. Sandstone, light gray, not notably carbonaceous.....	2 $\frac{1}{2}$
E. Sandstone, somewhat shaly and carbonaceous, like bed C.	4
F. Conglomerate and clay, reddish, purplish, and greenish. Purple beds almost wholly minute fragments of serpentine and basic igneous rocks. Pebbles largely flat fragments of Franciscan, rarely over 3 or 4 inches long	35-40
G. Sandstone, mainly shaly and carbonaceous, with a few massive concretionary beds. Somewhat like bed E.	
Base not exposed.....	15+

The beds lying beneath the coal and mapped as part of the Vaqueros formation have not yet yielded diagnostic fossils. At the Stone Canyon mine the coal rests upon clay shale somewhat different from any beds of the Vaqueros above the coal, and judged by this section alone there seems to be some ground for the view held by many who have examined the mine that the clay and coal are parts of a formation older than the Vaqueros. However, on the northeast side of the Diablo Range the carbonaceous beds are underlain in places by gravel and coarse sandstone precisely like those which overlie the coal and which contain typical lower Miocene fossils. Thus there seems to be no reason to doubt that the coal is of lower Miocene age, as it was regarded by Arnold.¹

Several prospect tunnels have been run into the lower part of the Vaqueros in the north half of secs. 33 and 34, T. 21 S., R. 13 E., in the valley of a stream tributary to Alum Creek. According to Mr. V. H. Crump the last work here was done in 1909, when a San Jose company ran a 200-foot tunnel to crosscut the coal. The tunnel

¹ Arnold, Ralph, Coal in the Diablo Range, Monterey County, Cal.: U. S. Geol. Survey Bull. 285, pp. 223-225, 1906.

started in beds a little below the massive calcareous sandstone of the Vaqueros and ran south about 200 feet into the Franciscan formation without finding coal. On the west side of the same creek near the line between secs. 33 and 34 are other caved prospect tunnels, which, to judge from the dump, were at least 200 or 300 feet in length. No definite information was available concerning them, but fragments of coal and carbonaceous shale lie in the dump. On the east side of the creek a prospect having about 200 feet of tunnel and incline was dug by Mr. Crump eight or nine years ago.

UPPER MIOCENE COAL.

Carbonaceous shale and thin beds of coal occur in the western end of the Priest Valley syncline, in T. 20 S., R. 12 E. On the south flank of the syncline outcrops of very carbonaceous shale and of coal are traceable from the southwest corner of sec. 25 northwestward through secs. 26, 27, 22, 21, and 17 to the center of the S. $\frac{1}{2}$ sec. 8, and thence eastward through secs. 9, 10, and 11 nearly to the center of sec. 14. The easternmost outcrop of these beds that was discovered on the north flank of this syncline occurs along the divide between Priest and Waltham valleys, although carbonaceous beds are reported to outcrop about a mile southeast of that divide, in the N. $\frac{1}{2}$ sec. 24.

The carbonaceous beds occur within 1,500 feet of the top of the upper Miocene. About 150 feet above them is a fossiliferous zone that contains abundant specimens of the scallop shells *Pecten watti*, *Pecten nuttteri*, and *Pecten coalingensis* and of *Thais* (*Purpura*) *etchegoinensis*. This fossiliferous zone occurs in the upper part of the Etchegoin formation in the Coalinga region. For the most part the carbonaceous beds form poor outcrops, weathering characteristically to a loose, deeply cracked clayey soil that supports a somewhat better growth of grass than the more sandy beds. They are probably best exposed south of Priest Valley post office, where the following section was measured:

Section of carbonaceous beds in NE. $\frac{1}{4}$ sec. 21, T. 20 S., R. 12 E., a quarter of a mile south of Priest Valley post office.

	Feet.
Sandstone, massive, gray, cross-bedded; fossiliferous zone containing <i>Thais</i> (<i>Purpura</i>) <i>etchegoinensis</i> , etc., in lower 50 feet.	275
Shale, greenish brown; contains numerous ironstone concretions and a thin bed of lignitic shale near base.	60
Sandstone, reddish gray, concretionary, poorly consolidated.	8
Shale, friable, greenish, stained reddish by iron.	11
Shale, brownish, carbonaceous, very fissile.	5
Shale, drab, carbonaceous.	1
Shale, brownish red, carbonaceous.	3

	Feet.
Shale, bluish, soft and fissile-----	4
Shale, brown, carbonaceous-----	6
Sandstone, gray, interstratified with fissile gray shale-----	15
Shale, soft and fissile; alternating bluish and brownish beds--	15
Sandstone, somewhat pebbly; a few thin beds of brown shale--	65
Shale, gray, iron stained; contains 2 to 4 inch beds of carbonaceous shale-----	70
Shale, brown, carbonaceous; thin partings of bluish shale-----	6
Not exposed (shale?)-----	70
Shale, poorly exposed; contains at least one bed of carbonaceous shale 2± feet thick-----	12
Shale, bluish gray, iron stained-----	28
Shale, brown, carbonaceous, with streaks of coal-----	5
Shale, light gray-----	3
Shale, carbonaceous, with streaks of coal-----	12
Shale, light gray, iron stained; bed of carbonaceous shale 1 foot thick near middle-----	85
Sandstone, yellowish, concretionary-----	7
Shale, brownish, carbonaceous, with streaks of coal-----	2
Shale, light gray, with yellowish concretionary layers-----	15
Shale (?); exposures poor but apparently show alternating thin layers of clay shale and carbonaceous shale; fairly definite 10-inch bed of brown carbonaceous shale near base--	25
Shale, light gray, iron stained-----	20
Shale, brown, carbonaceous, with streaks of coal-----	3
Not exposed (shale?)-----	20
Shale, light gray, iron stained, increasingly sandy toward base -----	100
Sandstone, gray, iron stained, massive, cross-bedded.-----	
	951

The coal beds in the Priest Valley syncline have been prospected at three places—in Coal Canyon, which is a tributary of Waltham Creek; in sec. 21, south of Priest Valley post office; and in sec. 17. The following notes regarding these prospects were obtained mainly from Mr. Thomas Hart, of Priest Valley.

The first prospecting was done about 20 years ago by Hart & Drabble on the north side of Coal Canyon, in sec. 22, T. 20 S., R. 12 E. They ran a 60-foot tunnel, known as the Drabble mine, in what they called the "small vein," a bed 3 or 4 feet thick in the upper part of the carbonaceous zone, which is rather sharply separated from the main part of the zone by gray sandstone. About 2 carloads of coal was taken out and hauled to the railroad. The mine was then sold to a Mr. Bush, of Hanford, who ran a crosscut, starting a few hundred feet below the Drabble tunnel. This crosscut was about 390 feet long in 1893 and had penetrated the following beds:¹

¹ California State Mining Bureau Thirteenth Rept. State Mineralogist, p. 53, 1896.

Beds penetrated in crosscut in Coal Canyon, Cal.

	Feet.
Soft gray sandstone.....	200
Light-blue compact clay.....	52
Coal bed No. 1, carbonaceous shale and seams of coal.....	4
Soft gray sandstone and shales.....	28
Gray compact argillaceous shale.....	7
Coal bed No. 2, coal and seams of shale.....	3
Sandy shales, passing into clay shales.....	96
	390

No more work was done until about 1907, when a company commonly known as the Monterey Coal Co., or the Pacific Coal & Clay Co., dug a 115-foot slope and a 35-foot tunnel in the ravine west of the old Bush and Drabble prospects. South of Priest Valley post office, in the NE. $\frac{1}{4}$ sec. 21, the same company dug a 60-foot slope and a 115-foot shaft, with 75 feet of drift at the bottom. In sec. 17, west of the post office, small pits have been dug along the outcrop of the coal. According to Mr. Hart, the coal weathers down rapidly into small platy fragments.

In secs. 20 and 21, T. 19 S., R. 11 E., about 4 miles southeast of Hepsedam, carbonaceous shale and thin coaly beds underlie an area of a little over half a square mile in a small syncline. These beds occur a few feet below the fossiliferous sandstone filled with *Pecten watti* that occurs above the coal in Priest Valley. A tunnel, which, according to Mr. Hart, is about 600 feet long, dug by the Pacific Coal & Clay Co., starts in beds that lie stratigraphically below the main carbonaceous beds but probably crosscuts them. At the time of visit this tunnel was not open and no coal was seen in the dump.



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
GEORGE OTIS SMITH, DIRECTOR

BULLETIN 581—E

THE COALVILLE COAL FIELD, UTAH

BY

CARROLL H. WEGEMANN

CONTRIBUTIONS TO ECONOMIC GEOLOGY, 1913, PART II—B



WASHINGTON
GOVERNMENT PRINTING OFFICE
1915

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COAL.

THE COALVILLE COAL FIELD, UTAH.

By CARROLL H. WEGEMANN.

INTRODUCTION.

One of the oldest coal-mining districts in Utah is situated about 30 miles northeast of Salt Lake City, in the vicinity of the little town of Coalville, which lies in the valley of Weber River. High-grade subbituminous coal has been mined in this district for over 50 years, and the mines now operating are large and well equipped. The coal beds, however, are involved in extensive rock folding and are broken by faults of considerable magnitude. The extent and limits of the coal-bearing area have therefore been in some doubt, and the present study was undertaken with the view not only of making a general geologic study of the area but of working out in detail the rock structure, correlating so far as possible the coal beds exposed at the several localities, outlining the probable productive area, and making estimates as to the depths of the coal beds within it.

The Coalville field as here defined is situated in Tps. 2 and 3 N., Rs. 5 and 6 E. Salt Lake principal meridian. The coal-bearing rocks of Colorado age have been brought to the surface by folding, which took place for the most part prior to the deposition of the great mantle of Tertiary conglomerate belonging to the Wasatch formation that covers much of this region. Later erosion has removed the Wasatch over part of the fold and exposed the underlying coal-bearing rocks, which, so far as surface exposures are concerned, are separated from all others of the same age.

The field work for this report was done by the writer late in September and early in October, 1911, and in September, 1912. Previous geologic work in the field and its mention in literature are briefly summarized below.

In 1859 Capt. J. H. Simpson made a reconnaissance of a broad territory including the Coalville field, and his results were published by the Engineer Department, United States Army, in a volume entitled "Explorations across the Great Basin of the Territory of Utah," containing a chapter on geology by Henry Engleman. A summary of his results also appeared in the Proceedings of the Academy of Natural

Sciences of Philadelphia for 1860. Clarence King discusses the stratigraphy and gives a description of the Coalville field and mining operations in the report of the United States Geological Exploration of the Fortieth Parallel, volume 1, chapter 4, section 3, and volume 3, chapter 7. Hayden describes the Coalville area briefly in his fourth annual report. Mention is made of mining operations near Coalville in a book entitled "Resources of Utah, 1879," published by the Utah Board of Trade, and in certain of the reports of the coal-mine inspectors of the State of Utah. In 1890 the stratigraphy of the region was worked out in detail by T. W. Stanton and published in Bulletin 106 of the United States Geological Survey. The economic resources of the area were examined by J. A. Taff and briefly summarized in a report on the "Weber coal field," published in Survey Bulletin 285. A. C. Veatch, in "Geography and geology of a portion of southwestern Wyoming" (United States Geological Survey Professional Paper 56), gives a short description of the Coalville section for comparison with the section in Wyoming. His report contains also a very complete bibliography, which should be consulted by anyone interested in the study of this general region.

TOPOGRAPHY.

The difference in altitude from the flood plain of Weber River to the crests of the high divides which shut in the valley of that stream is about 2,000 feet. These divides are composed of strata of the Wasatch formation, and in the vicinity of Coalville there are several escarpments of considerable height formed by sandstone beds of Cretaceous age, which are here brought to the surface on the crest of the fold already mentioned. (See Pl. VI.)

The principal stream of the area is Weber River, which flows from south to north past the town of Coalville, where it is joined from the east by Chalk Creek. Two miles north of Coalville a smaller tributary, known as Grass Creek, comes in from the northeast; and at Echo City, 5 miles northwest of Coalville, the Weber is joined by the stream of Echo Canyon, which flows southwest. The main line of the Union Pacific Railroad runs through Echo Canyon, and the Park City branch follows the Weber from Echo City to Park City. Spurs run to the mines on Grass Creek and Chalk Creek, in the Coalville field.

GEOLOGY.

STRATIGRAPHY.

The rocks exposed at Coalville comprise a stratigraphic section about 9,000 feet in thickness, but, although the area has been studied by several geologists, the formation boundaries are by no means definitely determined. A composite section, the parts of which were



A. VALLEY OF WEBER RIVER, UTAH, FROM THE EAST.

Town of Coalville on right. 1, Carleton mine; 2, Sargent mine; 3, Buell & Bateman mine; 4, sandstone (No. 4 of section, p. 163); 5, Wasatch formation unconformable on Cretaceous beds; 6, Cretaceous conglomerate. (See p. 177.)



B. VALLEY OF CHALK CREEK, UTAH.

Looking north from same viewpoint as that from which Plate VI, A was taken. Town of Coalville on left. 1, Location of Echo City; 2, fault (see top of p. 169); 3, minor fault; 4, outcrop of sandstone (No. 4 of section, p. 163); 5, Wasatch mine; 6, outcrop of sandstone (No. 9 of section).

measured at various places in the vicinity of Coalville, is presented below:

Stratigraphic section at Coalville, Utah.

	Feet.
1. Top. Conglomerate of Wasatch formation; as exposed in Echo Canyon over 1,000 feet thick but probably reaching much greater thicknesses in other localities; color, various shades of red; contains boulders 1 foot or less in diameter. Unconformable on all older formations...	1,000+
2. Soft beds, prevailingly sandy, usually concealed in grassy slopes; fossil leaves and fresh-water shells and thin beds of conglomerate occur at intervals.....	2,500
3. Beds prevailingly sandy but not well exposed; contain marine shells.....	1,650
4. Sandstone, white, coarse, forming the prominent ridge west of the town of Coalville and also north of Dry Hollow.....	200
5. Shale and thin beds of sandstone; at the base a coal bed, usually in two benches, formerly mined in Dry Hollow and at the Carleton mine.....	90
6. Shale.....	880
7. Conglomerate, brown; pebbles principally of limestone and sandstone, the largest 6 inches in diameter.....	40-100
8. Shale (lacking in some sections, the conglomerate resting directly on the underlying sandstone).....	180
9. Sandstone, forming the pronounced cliff just northeast of the town of Coalville, probably equivalent to the Oyster Ridge sandstone member of the Frontier formation of southwestern Wyoming.....	100-200
10. Shale, pink at base.....	750
11. Sandstone, in places conglomeratic.....	30-130
12. Coal bed, locally known as the "Wasatch" bed, mined at Coalville.....	5-12
13. Sandstone, in some sections very shaly.....	40-80
14. Shale and sandstone alternating, white and gray, with numerous beds of pink shale, especially toward the base.....	750
15. Coal beds, thin, three or four exposed in Spring Canyon, associated with carbonaceous shale.....	30
16. Shale, terra cotta in color, with three thin beds of white or gray sandstone.....	850
	9,250±

Stanton,¹ in his discussion of the formations of the area, states that fossils collected from the strata ranging from a horizon 100 feet below the thick bed of coal mined at Coalville to the bed of conglomerate about 1,000 feet above that coal belong to a single fauna, which is of Colorado age. This part of the section resembles faunally and lithologically the Frontier formation of southwestern Wyoming, later described by Veatch, and doubtless represents at least a part of that

¹ Stanton, T. W., The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, p. 40, 1893.

formation. Whether or not the beds for 1,000 feet above the conglomerate are also of Colorado age Stanton was uncertain at the time of the publication of his paper. Since then, however, he has come to believe that possibly the thin coal bed which lies about 2,000 feet above the thick bed at Coalville, together with the next higher sandstone bed (No. 4), should also be classed as Colorado. This belief is strengthened by some collections made by Veatch¹ in southwestern Wyoming, where the fossil *Inoceramus exogyroides*, which is characteristic of the Colorado group, was found at a horizon 3,000 feet above that of bed No. 4 of the Coalville section. Evidence against the Colorado age of this coal and associated beds is furnished by a collection of fossil leaves which Stanton obtained about 45 feet above the highest coal in the Coalville area. These leaves were at first assigned by Knowlton² to the Laramie but are now believed by him to be of Montana age. The later determination accords with Stanton's original statement that the top of the beds of Colorado age may be marked by the bed of conglomerate (No. 7) 1,000 feet above the thick coal bed at Coalville. The age of Nos. 2 and 3 of the section is also in doubt. The fossil collections indicate that No. 3 is marine. No. 2, up to the base of the conglomerate exposed on the Echo Canyon-Grass Creek divide, contains fossil leaves and fresh-water shells. Veatch describes a formation of shales and sandstones in southwestern Wyoming which he terms the Hilliard formation and which overlies the Frontier formation and is from 5,500 to 6,800 feet thick. This formation is marine, as indicated by the invertebrate fossils found at several horizons in it. It is probable that the coarseness of the materials, apparently occupying the same position at Coalville, is due to the fact that they were deposited nearer the shore line of the ancient land mass from which they were derived than the beds of southwestern Wyoming. This conclusion is supported by the sandy nature of the beds at Coalville that occupy the stratigraphic position of the Hilliard formation, and by the presence at Coalville of the conglomerate bed (No. 7) which is lacking in the Wyoming area, unless it is represented, together with the sandstone of No. 9, by the Oyster Ridge sandstone member of the Frontier formation, which is in some places conglomeratic. If the above-stated hypothesis is correct exact correspondence between the beds at Coalville, deposited in shallow water, and those in Wyoming, laid down farther from the ancient shore line, is not to be expected.

The conglomerate of Echo Canyon (Pl. VII, B) has been correlated by Veatch³ with the Almy formation of southwestern Wyoming, which appears to be conformable in that area on the underlying

¹ Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, p. 60, 1907.

² Knowlton, F. H., Flora of the Montana formation: U. S. Geol. Survey Bull. 163, p. 8, 1900.

³ Op. cit., p. 89.

Evanston formation. The Evanston is separated by a great unconformity from the underlying Adaville, which overlies the Hilliard. If divisions made in southwestern Wyoming could be applied to the Coalville section, there should be between the highest marine beds and the conglomerate of Echo Canyon two fresh-water formations, the Adaville and the Evanston, separated by a great unconformity. Unfortunately the base of the conglomerate in Echo Canyon is not well exposed on the Echo Canyon and Grass Creek divide and the fossils obtained from the beds underlying it are too few to serve as a basis of correlation.

The age of the 1,700 feet of strata below the thick coal bed mined at Coalville is also doubtful, as fossils are rarely found in them. A small collection obtained near the group of thin coal beds of No. 15 is said by Stanton to suggest Bear River, but from the stratigraphic relations exhibited in the field these beds seem to be several thousand feet higher in the section than the Bear River.

From Stanton's observations near Rockport, Utah, 12 miles south of Coalville, there appear to be 4,700 feet of beds between the Coalville coal and the horizon that corresponds with the top of the Aspen formation in southwestern Wyoming, which in turn overlies the Bear River where that formation is present.¹ In view of this fact, the occurrence of fossils suggesting the Bear River only 850 feet below the Coalville coal is worthy of note. In southwestern Wyoming the lower beds of the Frontier do not have the pink and red tints which are exhibited by the lowest beds exposed in the Coalville area.

From such evidence as is given above it is perhaps unsafe to draw any conclusions, but it seems probable that the beds exposed at Coalville from the base of the section at least to the conglomerate 1,000 feet above the "Wasatch" coal bed mined at Coalville are of Colorado age and belong to the Frontier formation. From the evidence of the plants collected by Stanton above the upper coal at Coalville it seems necessary to infer that the strata above No. 6 are not older than the Montana group and probably include the equivalent of part at least of the Hilliard formation described by Veatch. If, however, the evidence of the invertebrates is considered without reference to that furnished by the fossil plants, the line between the Colorado and Montana should probably be drawn considerably higher in the section, as suggested by Veatch—somewhere in the strata above the sandstone of No. 4. If it were drawn 1,200 feet above this sandstone it would mark the transition from marine to fresh-water deposits.

The following list of fossils with determinations and notes by T. W. Stanton, F. H. Knowlton, and W. H. Dall is given as bearing on the

¹ Op. cit., p. 44.

age of the rocks exposed at Coalville. For a full discussion of the paleontology of the region reference should be made to Stanton's work, already cited.¹

Four miles north of Coalville, in sec. 21, T. 3 N., R. 5 E., about 630 feet below the base of the conglomerate in Echo Canyon:

Quercus sp.

Ficus pseudo-populus Lesquereux. A form regarded by Knowlton as post-Laramie, described originally from specimens obtained at Evanston and Green River, Wyo.

Ficus planicostata Lesquereux. Occurs in beds at Black Buttes, Wyo., regarded by Knowlton as of post-Laramie age.

Seven miles northeast of Coalville, in the SW. $\frac{1}{4}$ sec. 33, T. 3 N., R. 6 E., 210 feet above base of No. 2 of the section on page 163:

Small narrow leaves not well preserved, probably *Salix* or *Sapindus*.

About $1\frac{1}{2}$ miles south of Coalville, in the NW. $\frac{1}{4}$ sec. 21, T. 2 N., R. 5 E., near the base of the Wasatch formation:

Land snail of the genus *Polygyra*, undescribed. Much more like the recent *Polygyras* than any of the Eocene species heretofore described from the western Tertiary.

In Clark's Canyon, 8 miles northeast of Coalville, upper surface of sandstone of No. 4:

Ostrea soleniscus Meek. This species has a great vertical range.

Fewkes Canyon, 7 miles northeast of Coalville, from No. 4 sandstone:

Ostrea coalvillensis Meek?

Inoceramus sp., possibly *I. erectus* Meek.

Judd Canyon, 7 miles northeast of Coalville, about the horizon of sandstone of No. 3:

Ostrea coalvillensis Meek.

Avicula sp.

Barbatia sp.

Corbicula sp.

Cardium sp.

Mactra arenaria Meek.

Corbula sp.

Chemnitzia sp.

Melania sp.

East of Huff Creek, 3 miles north of Upton, from 20-foot bed of oysters above coal bed:

Ostrea coalvillensis Meek. This species is associated with the coal bed of No. 5 and is probably confined in the Coalville field to that part of the section.

Three miles east of Upton, in Judd Canyon, about 400 feet above the base of No. 3:

Ostrea sp.

Inoceramus erectus Meek.

About $2\frac{1}{2}$ miles above the mouth of South Fork of Chalk Creek, in the SW. $\frac{1}{4}$ sec. 11, T. 2 N., R. 6 E., from an isolated exposure of Cretaceous rocks on the north side of the creek:

Inoceramus labiatus Schlotheim.

Tellina modesta Meek?

Mactra emmonsii Meek?

Probably from a horizon higher than that of the "Wasatch" coal bed (No. 12). This collection has a bearing on the probable position of the "Wasatch" coal in this area, which is for the most part covered by Wasatch.

¹ The Colorado formation and its invertebrate fauna: U. S. Geol. Survey Bull. 106, 1893.

Half a mile south of Coalville, about 30 feet below the "Wasatch" coal bed (No. 12):

Ostrea soleniscus Meek.

Tellina modesta Meek.

Glaucania coalvillensis Meek.

These species belong to the fauna of the Colorado group and indicate a zone included in the Frontier formation in western Wyoming.

Three miles east of Coalville, in the NE. $\frac{1}{4}$ sec. 11, T. 2 N., R. 5 E., from strata apparently just below coal beds of No. 15:

Ostrea soleniscus Meek.

Modiola multilinigera Meek.

Barbatia micronema (Meek).

Horizon in the Colorado group, probably below the "Wasatch" coal bed (No. 12).

A quarter of a mile northeast of the last collection, in the SW. $\frac{1}{4}$ sec. 1, T. 2 N., R. 5 E., from strata between coal beds of No. 15:

Ostrea sp.

Corbicula durkeei Meek?

Pachymelania? sp.

Pyrgulifera sp.

This little collection is strongly suggestive of the Bear River fauna, but none of the fossils can be identified as typical specimens of Bear River species, and the collection is too meager to justify any positive statements about it. With the possible exception of the *Ostrea* it shows nothing in common with the preceding collection.

Two miles up Spring Canyon, in the NW. $\frac{1}{4}$ sec. 26, T. 2 N., R. 5 E., from sandstone ledge below coal beds supposed to belong to No. 15:

Ostrea sp.

Anomia sp.

Modiola multilinigera Meek?

Cardium? sp.

Cyrena? sp.

So far as can be determined from these fossils the horizon might be either near the local base of the Cretaceous or in No. 5.

STRUCTURE.

The structure of the rocks in the Coalville area is that of a slightly overturned anticline. (See Pls. VIII, A, and XI.) On the northwest limb of this anticline the beds rise toward the southeast with dips of 15° to 30° and strike of N. 47° E., flatten rather abruptly on the broad, flat top of the fold, and descend precipitously on the southeast side with a strike of about N. 20° E. The whole thickness exposed at the surface, or about 9,000 feet, is involved in the fold, the coal descending in the syncline on the southeast from a surface altitude of 6,500 feet to approximately 500 feet below sea level and rising again to the surface about 4 miles east of the anticline, on the northwest flank of a second fold which is probably connected on the north with the folds southwest of Evanston, Wyo. The south end of the Coalville anticline is obscured by the overlying Wasatch formation.

Several miles northwest of the Coalville anticline another and more abrupt fold brings the Cretaceous rocks to the surface in the valley of Weber River, 2 or 3 miles below Echo City. The fold is

very narrow and apparently parallels that at Coalville. Whether or not this is the continuation of a fold which appears on Lost Creek, 15 miles northwest of the Coalville field, is uncertain. Lost Creek flows in what is apparently an anticlinal valley, the coal-bearing Cretaceous rocks being exposed well up in the hills on each side. Between the Lost Creek and Coalville anticlines lies the syncline of Echo Canyon, which involves to some extent the strata of the Wasatch and is probably much more pronounced in the underlying Cretaceous formations. (See Pl. VII, *B*.)

In the Coalville anticline, north of the town of Coalville, the beds strike about N. 35° E. Near the town, however, the strike changes, so that in the vicinity of the Sargent mine, on the west side of the Weber, it is N. 19° E. The upper beds hold the same strike for about a mile farther south to the point where they are covered by the overlying Wasatch deposits. (See Pl. VI, *A*.) They give no indication of a minor fold which involves the lower beds just southeast of the town of Coalville. The outcrop of the principal bed of coal, the "Wasatch" bed, formerly mined at the town, takes a direction approximately north and south at the old Buell & Bateman mine and, swinging to the southeast, is opened at the mine of the Superior Fuel & Briquette Co. From this place it swings to the northeast and east, thus outlining the small fold above mentioned, and is opened on the north end of the adjoining syncline at the old Howard mine in the NW. $\frac{1}{4}$ sec. 15. From this opening it can be traced a short distance to the southeast but is soon lost under the cover of Wasatch. It probably turns again in a south or southwest direction to conform with the strike of the coal beds exposed in Spring Canyon, but how far south it may extend before connecting with the outcrop marking the southeast side of the fold it is impossible to determine. The coal beds in Spring Canyon (Pl. VIII, *B*) appear from their position and the character of the associated strata to represent those north of The Narrows at Chalk Creek, which lie 850 feet below the "Wasatch" coal bed exposed at the Hoffman mine. (See Pl. VIII, *A*.) If the coal in Spring Canyon really belongs to this lowest coal group the anticline probably continues for a considerable distance farther south and may be directly connected with the anticline which crosses Weber River $1\frac{1}{2}$ miles south of Wanship.

A little north and east of Coalville, at about the middle of the fold, a block of strata 2 miles in width from northeast to southwest has been dropped by faulting with reference to the adjacent beds. The faults bounding this block on the northeast and southwest are by no means simple ones. On the southwest four distinct faults may be observed distributed through a distance of $1\frac{1}{2}$ miles, the downward movement of the central block being thus distributed along four



A. VIEW LOOKING NORTHEAST IN SEC. 28, T. 3 N., R. 6 E., UTAH.

Sandstone (No. 4 of section, p. 163) in vertical position. Abrupt turn of "Wasatch" coal bed (No. 12 of section) at northeast end of anticline shown by dotted line on left.



B. VIEW LOOKING WEST ACROSS ECHO CANYON, UTAH, NEAR ITS MOUTH.

Cliffs of conglomerate of Wasatch formation, the strata of which dip northwest into a syncline which adjoins the Coalville anticline.



A. LOOKING NORTH ACROSS CREEK FROM HILL IN SEC. 18, T. 2 N., R. 6 E.

Heavy line drawn on sandstone bed below coal (No. 15 of section, p. 163) outlines in cross section the crest of the anticline. Broken lines show position of "Wasatch" coal bed. In the distance its course with low dip around pitching end of anticline is indicated. (See p. 181.) 1, Clark prospect; 2, Hoffman mine; 4, sandstone (No. 4 of section, p. 163); 9, sandstone (No. 9 of section) in vertical position; 15, coal bed (No. 15 of section).



B. LOOKING NORTHWEST FROM THE NARROWS.

1-1, 2-2, Wasatch formation filling a pre-Wasatch stream valley and bounded on either side by lighter-colored strata of Colorado age. (See p. 171.)
VALLEY OF CHALK CREEK, UTAH.

different lines of fracture, although greatest along that shown in Plate VI, *B*. The fault bounding the displaced block on the northeast is apparently a simple fracture where it crosses Grass Creek, but a short distance to the south it breaks up into a number of faults, as is shown by an isolated mass of coal set off on each side by faults in the middle of sec. 27, T. 3 N., R. 5 E. (See Pls. VIII, *B*, and XI.) Numerous small faults have been noted in the northeastern workings of the Wasatch mine in the NE. $\frac{1}{4}$ sec. 3, T. 2 N., R. 5 E., and it is probable that these faults will be found to increase in size as the great fault is approached. The flattening of the rocks on the crest of the fold, which is approximately 3 miles in width, accounts for the fact that whereas the upper coal on Grass Creek is displaced less than half a mile by the great fault which crosses secs. 23, 26, and 35, T. 3 N., R. 5 E., the lower bed outcropping farther to the southeast and thus nearer to the top of the fold is displaced by the same fault a horizontal distance of over 2 miles. (See Pl. XI.) The movement was probably vertical, the block southwest of the fault being dropped, and the horizontal displacement may thus be accounted for by a movement of only a few hundred feet in the gently dipping beds near the crest of the fold. The trace of the fault to the south is somewhat uncertain. It is possible that the abrupt change in dip at The Narrows, in the SW. $\frac{1}{4}$ sec. 12, T. 2 N., R. 5 E., is in line with it, but whether or not it passes between the coal exposures in the SW. $\frac{1}{4}$ sec. 1 and the NE. $\frac{1}{4}$ sec. 11 of the same township is undetermined.

The abrupt change in strike of the rocks at the northeast end of the fold is noteworthy. The beds on Grass Creek strike approximately N. 50° E., and this strike changes abruptly near the mine of the Union Fuel Co. to S. 52° E. Holding this direction for about 2 miles across the northeast end of the field, it again changes abruptly at the old prospects in Fewkes Canyon to S. 36° W., the two bends thus produced being almost right angles. (See Pls. VIII, *A*, and XI.)

The periods of folding and faulting in this region can be fairly well determined. Except for the unconformity marked by the conglomerate 1,000 feet above the principal Coalville coal, the series of strata 9,000 feet thick exposed in this area appears to be conformable. It is evident from the comparative regularity of the beds underlying the conglomerate that the deposition of these beds was not preceded by any great amount of erosion or any period of folding. The unconformity at the base of the Wasatch, which overlies the other formations exposed in this area, is great and is probably to be correlated in part at least with the great unconformity at the base of the Evanston formation in southwestern Wyoming, which is said

by Veatch¹ to denote "a long period of folding, faulting, and erosion," indicating in the Wyoming area an unconformity of over 20,000 feet. It seems fair to assume, therefore, that the folding and faulting that are apparent in all the rocks exposed at Coalville below the conglomerate of the Wasatch formation took place during the period denoted by this unconformity. Certainly they took place after the deposition of the lower part of No. 2 in the stratigraphic section given on page 163 (the upper part is not well exposed) inasmuch as these beds were involved in the movement, and they took place for the most part before the deposition of the conglomerate, for the Wasatch strata are but little disturbed in comparison with the strata on which they rest.

It is true that a certain amount of movement took place after the deposition of the Wasatch, and this movement appears to have been in the main, though not invariably, along the same lines of weakness as that which preceded the deposition. For example, the syncline of Echo Canyon, into which the Cretaceous strata on the northwest flank of the Coalville anticline dip at an angle of 29° is indicated in the overlying Wasatch by a comparatively gentle structure. (See Pl. VII, B.) Southeast of Coalville, in sec. 22, T. 2 N., R. 5 E., just north of Spring Canyon, strata of the Wasatch formation dip 7° NW. The strike exactly parallels the strike of the older beds which outcrop three-quarters of a mile farther up the canyon and dip at an angle of 26° . (See Pl. VIII, B, and XI.) Wasatch beds exposed in sec. 25, T. 2 N., R. 4 E., dip 7° S. and strike east, whereas the older rocks exposed 1 mile to the north dip 10° – 15° NW. and strike approximately N. 20° E. (See Pl. VI, A, and XI.) If an east-west fault with downthrow on the south had broken the strata at this place prior to the deposition of the Wasatch beds, and if movement along the same fault plane had taken place subsequent to the deposition, just such conditions might have resulted. The same dip might, however, have resulted from a post-Wasatch uplift of the major part of the dome without faulting, so that the presence or absence of a fault here is undetermined. In the NE. $\frac{1}{4}$ sec. 2, T. 2 N., R. 5 E., near the line of the great fault which crosses that section, Wasatch beds dip at an angle of 20° , which is unusually great in comparison to the dip of these beds in other parts of the field. It seems probable that post-Wasatch movement along the line of the great fault has produced the unusual dip, but it is also probable that the major movement along this fault plane took place prior to the Wasatch deposition, as, except for the increase in dip at this one locality, there is no surface evidence in the Wasatch formation of the presence of this fault, although the underlying Cretaceous beds give abundant

¹ Veatch, A. C., Geography and geology of a portion of southwestern Wyoming, with special reference to coal and oil: U. S. Geol. Survey Prof. Paper 56, p. 75, 1907.

proof of its existence. In sec. 36, T. 3 N., R. 6 E., the coal bed at the Boyer mine dips 12° W., and the overlying beds of the Wasatch are practically horizontal. About a mile above the south fork of Chalk Creek beds near the top of the Cretaceous section stand on edge, although just south of the stream the beds of the Wasatch formation are horizontal.

It seems evident, therefore, that two periods of movement are represented in the Coalville region. The first or more extreme deformation took place after the deposition of the topmost Cretaceous strata exposed in this area and before the deposition of the conglomerate of the Wasatch formation, and the second and lesser deformation occurred some time after the deposition of the Wasatch, the movement as a rule merely accentuating the folds and faults already formed in the older rocks.

That considerable erosion took place before the deposition of the conglomerate of the Wasatch formation is shown by the fact that undisturbed strata of the Wasatch may be found in some of the larger river valleys much below Cretaceous beds that outcrop on adjacent highlands. As the conglomerate of the Wasatch is more resistant to erosion than the Cretaceous strata, it forms many of the highest eminences in the region and not uncommonly the Wasatch filling of a pre-Wasatch river valley forms a line of hills. Such a condition seems to exist 2 miles northeast of Coalville, along the series of faults above mentioned, which cross the divide from Chalk Creek to Grass Creek. Along the zone of weakness formed by these faults a valley was excavated by erosion in pre-Wasatch time. This valley was afterward filled by gravel and boulders, subsequently consolidated into the conglomerate of the Wasatch formation which may at the present time be observed outcropping at many points lower than the Cretaceous strata. (See Pl. VIII, *B*.) The fact that the Dry Hollow coal bed does not outcrop south of the old Carleton mine is probably due, in part at least, to erosion prior to the deposition of the Wasatch sediments, and the same may be said of the principal bed south of the old Howard mine.

THE COAL.

GENERAL CHARACTER.

Three beds of coal are present in the Coalville field. The principal one is that mined on Grass Creek and at the Wasatch mine of the Weber Coal Co. and the mine of the Superior Fuel & Briquette Co. It is usually referred to as the "Wasatch" bed. The second in importance, the Dry Hollow bed, occurs about 2,000 feet above the principal bed and was formerly worked along Dry Hollow north of Coalville and at the old Carleton mine, in sec. 19. The lowest bed or

group of beds is that which is exposed in the prospects in Spring Canyon, in sec. 26, and will be termed for convenience the Spring Canyon bed. It is doubtfully correlated with the coal exposed in the same township north of Chalk Creek, in the SW. $\frac{1}{4}$ sec. 1, which is 850 feet below the "Wasatch" bed.

At the time of this examination it was possible to obtain fresh material for analysis only from the "Wasatch" bed. Three analyses of this coal are given in the following table, together with one analysis of bituminous coal of Frontier age from Cumberland, Wyo., and two of sub bituminous coals, one from the Evanston formation of southwestern Wyoming and one from the Fort Union formation of the Sheridan field, in north-central Wyoming.

In the table the analyses are given in four forms, marked A, B, C, and D. Analysis A represents the composition of the sample as it comes from the mine. This form is not well suited for comparison, because the amount of moisture in the sample as it comes from the mine is largely a matter of variable local conditions, and consequently analyses of the same coal expressed in this form may vary widely. Analysis B represents the sample after it has been dried at a temperature a little above the normal until its weight becomes constant. This form of analysis is best adapted for general comparison. Analysis C represents the theoretical condition of the coal after all the moisture has been eliminated. Analysis D represents the coal after all the moisture and ash have been theoretically removed. This is supposed to represent the true coal substance, free from the most abundant impurities. Forms C and D, which are obtained from the others by recalculation, represent theoretical conditions that do not exist.

In the analytical work it is not possible to determine the proximate constituents of coal or lignite with the same degree of accuracy as the ultimate constituents. Therefore the air-drying loss, moisture, volatile matter, fixed carbon, and ash are given to one decimal place only, whereas the ash (in the ultimate analysis), sulphur, hydrogen, carbon, nitrogen, and oxygen are given to two decimal places. The determination of the calorific value to individual units is not reliable, hence in the column headed "Calories" the heat values are given to the nearest five units, and in the column headed "British thermal units" they are given to the nearest tens, as the value of a British thermal unit is about one-half that of a calorie.

Analyses of coal samples from the "Wasatch" bed, Coalville field, Utah, and of Wyoming coal from various fields.

[Made by U. S. Geological Survey and the Bureau of Mines.]

Laboratory No.	Name and location of mine.	Collector.	Coal bed and kind of coal.	Location.			Thickness.		Air-drying loss.	Form of analysis.	Proximate.			Ultimate.					Heating value		
				Quarter.	Section.	Township.	Range.	Coal bed.			Part sampled.	Moisture.	Volatile matter.	Fixed carbon.	Ash.	Sulphur.	Hydrogen.	Carbon.	Nitrogen.	Oxygen.	Calories.	British thermal units.
13216	Mine operated by Tom Reese-Grass Creek Coal Co., 6 miles northeast of Coalville, Utah.	Carroll H. Wegemann.	"Wasatch" coal bed, subbituminous.	NW. 24	3 N.	5 E.		8 ft. 8 in.	8 ft. 8 in.	A	12.2	42.2	42.2	3.39	1.90	5.80	63.77	23.87	20.81	6,255	11,260
										B	8.0	44.2	44.2	3.55	1.99	5.55	66.77	20.81	20.81	6,560	11,760
										C	48.0	48.1	48.1	3.86	2.16	5.07	72.61	14.85	14.85	7,120	12,820
										D	50.0	50.0	50.0	.....	2.25	5.27	75.52	15.45	15.45	7,405	13,330
13217	Mine operated by Superior Fuel & Brickette Co., 1 mile southeast of Coalville, Utah.	do.....	do.....	SW. 16	2 N.	5 E.		7 ft. 6 in.	7 ft. 6 in.	A	17.1	36.9	41.2	4.8	1.53	.....	.....	.....	.....	5,655	10,179
										B	10.1	40.1	44.7	5.1	1.66	.....	.....	.....	.....	6,135	11,040
										C	44.6	49.7	5.7	1.85	.....	.....	.....	.....	.....	6,820	12,280
										D	47.3	52.7	.....	.....	1.96	.....	.....	.....	.....	7,265	13,020
13218	Mine operated by Weber Coal Co., 14 miles northeast of Coalville, Utah.	do.....	do.....	SW. 3	2 N.	5 E.		10 ft. 6 in.	10 ft. 6 in.	A	13.6	41.3	41.0	4.08	1.37	5.84	62.11	1.06	25.54	6,100	10,980
										B	8.8	43.6	43.3	4.31	1.45	5.54	65.59	1.12	21.99	6,440	11,500
										C	47.8	47.5	4.72	1.59	5.01	71.89	1.23	15.56	7,060	12,710	
										D	50.2	49.8	.....	.....	1.67	5.26	75.45	1.29	16.33	7,410	13,340
2245	Cumberland mine No. 1, Union Pacific Coal Co., 1 mile west of Cumberland, Lincoln County, Wyo.	A. C. Vesten.	Main Kemmerer coal bed, bituminous.	SW. 31	19 N.	116 W.		8 ft. 0 in.	8 ft. 0 in.	A	6.8	30.8	47.4	6.00	.43	5.66	69.01	1.19	17.88	6,815	12,370
										B	4.3	40.8	48.7	6.16	.44	5.41	70.85	1.15	15.99	6,965	12,500
										C	42.7	50.9	6.44	.46	5.16	74.03	1.20	12.71	7,310	13,160	
										D	45.6	54.4	.....	.49	5.51	79.12	1.28	13.60	7,815	14,060	
2325	Mine No. 5, Rocky Mountain Coal & Iron Co., near Almy, Uinta County, Wyo.	do.....	Main Almy coal bed, subbituminous.	SE. 30	16 N.	120 W.		24 ft. 0 in.	8 ft. 0 in.	A	14.4	36.8	41.6	7.22	.21	5.37	69.97	1.15	26.08	5,805	10,450
										B	8.3	39.5	44.5	7.74	.22	4.96	64.28	1.23	21.57	6,220	11,200
										C	43.0	48.5	8.44	.25	4.41	70.08	1.34	15.48	6,785	12,310	
										D	47.0	53.0	.....	.....	.27	4.81	76.54	1.47	16.91	7,410	13,330
12685	Mine operated by Monarch Coal Co., Monarch, Sheridan County, Wyo.	O. B. Hopkins.	Monarch coal bed, subbituminous.	.....	.....	.....		.....	.....	A	23.9	34.3	38.4	3.35	.38	6.29	54.07	1.14	34.77	5,185	9,335
										B	17.2	37.4	41.8	3.65	.41	5.87	58.94	1.24	29.99	5,645	10,160
										C	45.1	50.5	4.40	.50	4.78	71.03	1.03	17.79	6,815	12,260	
										D	47.2	52.8	.....	.....	.52	5.60	74.30	1.57	18.61	7,125	12,880

It will be seen from the above analyses that although the coal is high in heating value, ranging from 11,039 to 11,788 British thermal units, it is also high in moisture content. It crumbles or slacks on exposure to the air and sunlight, and is therefore to be classed as a subbituminous coal. It is interesting to note that coal of the same age near Cumberland, in southwestern Wyoming, 75 miles northeast of Coalville, is bituminous in grade, differing from that of Coalville in its lower percentage of moisture and in its ability to withstand exposure without crumbling. The Coalville coal is dense and brittle and is generally black in color but has in certain lights a somewhat brownish cast. It is low in ash and its luster is vitreous. The powder is black. The bedding is massive, but when mined the coal breaks with a fairly good cleavage in two planes almost at right angles to each other.

THE COAL BEDS BY TOWNSHIPS.¹

T. 3 N., R. 5 E.

"Wasatch" coal bed.—The northernmost mine on the "Wasatch" bed in T. 3 N., R. 5 E., is the Tom Reese-Grass Creek mine, in the SW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 12. The coal is here from 7 to 10 feet thick, without partings of any kind. At the mouth of the slope the sandstone which overlies the coal dips 34° NW., contains numerous conglomeratic layers, and is from 25 to 30 feet thick. In the mine there are places where shale appears to come in between the coal and the overlying sandstone, so that the roof of the coal is at these localities formed by shale. Considerable difficulty is encountered by the "heaving" of the shale floor, which in some places amounts to as much as 5 feet. The capacity of the mine is from 150 to 200 tons a day. The method of mining is in general that employed by all the mines in this area, a slope being run down the dip of the coal bed and the entries being driven along the strike of the bed with just enough inclination toward the slope to allow free drainage. The rooms are turned up the slope from the entries.

Three-quarters of a mile southwest of the Tom Reese mine are some abandoned mines formerly worked by the Union Pacific Co. In sec. 14 the "Wasatch" bed is broken by a normal fault trending a little east of south. Although the vertical displacement of this fault may not be great, the outcrop of the coal, because of the flattening of the anticline near its crest, is displaced horizontally more than 2 miles, the bed reappearing in the NW. $\frac{1}{4}$ sec. 2, T. 2 N., R. 5 E. Where the fault cuts the sandstone ledges in the southern part of sec. 23, T. 3 N., R. 5 E., it appears as a simple break, but south of this point it apparently divides, the movement being distributed

¹ In the following descriptions frequent reference should be made to the general map, Pl. XI.

along several planes approximately parallel to one another. This division is shown by the isolated mass of coal outcropping in Bull Hollow, near the center of sec. 26 of this township, which is separated by a fault from the outcrop of the main bed on the northeast and by a second fault from the outcrop of the main bed on the southwest. This isolated mass was formerly worked and yielded considerable coal.

Dry Hollow coal bed.—The Dry Hollow bed, occurring about 2,000 feet stratigraphically above the "Wasatch" bed, has been prospected at several places just north of the road in secs. 26 and 27, but no extensive mining has been done. The bed is reported to lie in two benches, the thicker of which is from 2 to 2½ feet thick. Because of the caving of the old prospects it was impossible to obtain an accurate measurement. In the southern part of sec. 27 the coal outcrop may be traced across the road and southward up the slope into Dry Hollow, the change in direction of the outcrop being due in some degree to a bend or slight fold in the strata, but for the most part to the difference in altitude on the Grass Creek and Dry Hollow divide. Along Dry Hollow the bed was formerly mined to a slight extent in several places, and a partial section of the bed measured at an old prospect in sec. 33 is as follows:

Section of coal bed in Dry Hollow.

Shale, carbonaceous.....	Ft. in.
Coal.....	2 2
Shale.....	1½
Coal.....	5
Shale, brown, with streaks of coal.....	1 0
Shale, gray.....	3 0
Coal, thickness undetermined, probably not over 20 inches.	
	6 8½

The bed in Dry Hollow dips 23° NW. and in the SE. ¼ sec. 33 is broken by a small fault, the downthrow being on the northeast side. A similar fault occurs in the SW. ¼ of the same section, near the township line.

Northeast of the great fault in the eastern part of the township already described, the Dry Hollow coal has not been found, although the sandstone which occurs about 100 feet above the bed can be followed along the slope northwest of the Tom Reese mine. The bed probably occurs in this locality, but it may perhaps have thinned or been replaced to some extent by carbonaceous shale, so that its outcrop is not easily observed. A bed believed to lie approximately at the same horizon outcrops 8 miles to the east, in the NE. ¼ sec. 13, T. 3 N., R. 6 E., where it is about 2 feet thick. The bed has not

been found in the interval between these exposures, unless the coal bed 18 to 24 inches thick in the SE. $\frac{1}{4}$ sec. 16, T. 3 N., R. 6 E., is at this horizon, which seems rather doubtful as it is immediately overlain by a bed of sandstone which forms a rather pronounced escarpment.

T. 2 N., R. 5 E.

"Wasatch" coal bed.—The northernmost opening of the "Wasatch" bed in T. 2 N., R. 5 E., is at the old Wilson mine, in the NW. $\frac{1}{4}$ sec. 2, which is now abandoned. The Wasatch mine, the most extensive and the oldest working mine in the field, is situated in the SW. $\frac{1}{4}$ sec. 3. The coal ranges from 9 to 13 feet in thickness and is without shale or bone partings. The dip of the bed is about 10° WNW. A number of minor faults having an upthrow on the northeast are encountered in the mine, especially in its northeast entries, and the coal adjacent to them is shattered to some extent, increasing the percentage of slack, which is separated by screening. The capacity of the mine is about 500 tons a day. The outcrop of the "Wasatch" bed extends from the Wasatch mine south-southwestward into the NW. $\frac{1}{4}$ sec. 10, where it is broken by a fault with a downthrow on the northeast, the outcrop being displaced half a mile horizontally and reappearing in the SE. $\frac{1}{4}$ sec. 4, where it was formerly worked in the Allen Hollow mines, now abandoned. It is reported that considerable faulting was encountered in these mines, the principal movement having taken place along a comparatively narrow fault zone and being the equivalent of that which was distributed among the four faults which break the Dry Hollow coal to the northwest at intervals of about half a mile.

The outcrop of the "Wasatch" bed is concealed across the flood plain of Chalk Creek but is exposed in the town of Coalville, where the bed was formerly worked at the Buell & Bateman mine in the NW. $\frac{1}{4}$ sec. 16, which is probably the same as the Sprague mine described by Clarence King¹ as having been worked in 1869. King states that at the Sprague mine the coal "averages 11 to 14 feet in thickness, resting on a cream-colored sandstone and roofed by thin strata of the same material, which passing upward alternate with bands of shale and sandstone." The mine was overburdened with water at a depth of 50 feet, which marked the lowest workings. The bed dipped 14° W. A report is current in Coalville to the effect that the "Wasatch" bed was found to thin abruptly to the west in the Buell & Bateman mine, the coal being cut out by a "sand roll" or deposit of coarse sand and gravel in the roof of the bed. Considering the swiftness of the water currents by which the sandstone above the coal was deposited, as shown by the coarseness of the material,

it is not unlikely that the coal was eroded to some extent in certain localities before the deposition of the overlying sandstone and conglomerate. It is not probable, however, that such erosion was extensive or that the character of the coal bed was affected by it over any considerable area.

The depth of the coal below the surface on the west side of the river has been variously estimated. In the NE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 17 a bed of conglomerate is exposed, which may represent the conglomerate of No. 7. (See Pl. VI, A.) It appears to be, however, 1,300 feet below the coal at the Sargent mine, whereas on Grass Creek the base of conglomerate No. 7 is only 950 feet below the Dry Hollow coal, which is taken to be the same bed as that exposed at the Sargent mine. If the structure between the exposure of conglomerate in sec. 17 and the Sargent mine is regular and the measurement of 1,300 feet therefore correct, it must be supposed either that the thickness of the shale of No. 6 is much greater on the west side of the river than on Grass Creek, or that the conglomerate exposed in sec. 17 is lower than No. 7, being perhaps a conglomeratic phase of sandstone No. 9. In the latter case the "Wasatch" coal bed is only about 750 feet below the surface at the outcrop of the conglomerate. If the conglomerate is in reality that of No. 7, the coal is probably 1,100 feet below its base. The drill alone can solve the problem. At the Sargent and Carleton mines, as well as at all outcrops of the Dry Hollow coal, the "Wasatch" bed is a little more than 2,000 feet below the surface, as the stratigraphic interval between the two beds is approximately that amount.

A short distance south of the Buell & Bateman opening and west of the road a shaft, now filled with water, has been sunk to the coal. From this place to the mine of the Superior Fuel & Briquette Co., a distance of three-fourths of a mile, the coal outcrop is concealed in the flood plain of Weber River. From dip and strike readings taken on thin beds of calcareous sandstone known as the "Diamond rock," which underlie the "Wasatch" bed at a distance of about 30 feet, it is evident that the outcrop of the coal swings somewhat sharply to the east in the SE. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 16. At the Superior Fuel & Briquette Co.'s mine the coal bed strikes N. 48° E. and dips to the south. The bed here ranges from 7 to 9 $\frac{1}{2}$ feet in thickness, but the percentage of slack in the coal is considerably increased by numerous small faults that are encountered at several places in the mine. The capacity of the mine is about 150 tons a day. The coal is overlain by 2 feet of shaly sandstone, 6 inches of shale containing numerous shells, and 10 inches of calcareous sandstone, overlying which is a bed of conglomeratic sandstone 30 or 40 feet thick. From the Superior Fuel & Briquette Co.'s mine the outcrop of the coal swings northeastward for

a distance of half a mile to the old Dexter mine, in the NE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 16. The strike is here about north and the dip 21° E. The Dexter mine, which is now abandoned, is one of the old mines of the field and from it, to judge by the size of the slack piles, a considerable amount of coal was removed. North of this mine the outcrop is concealed, but it apparently extends north and then east, outlining the syncline described on page 168, to the old Howard mine, in the NW. $\frac{1}{4}$ NW. $\frac{1}{4}$ sec. 15, where it strikes N. 69° W. and dips 16° SSW. Only a small amount of coal was removed at the Howard mine, which has long since been abandoned. From this place the outcrop probably swings to the southeast and then south, but its exact location is uncertain. An outcrop of white sandstone, believed to be the bed overlying the coal, appears 800 feet southeast of the old mine opening, but to the southeast the coal-bearing rocks are concealed by the cover of conglomerate of the Wasatch formation. Whether or not the coal in the syncline in the western part of sec. 15 and the eastern part of sec. 16 is broken by faulting, it is impossible to say. The Union Pacific Coal Co. has put down a number of drill holes in this area, but no definite information could be obtained concerning them. It is reported at Coalville that coal was struck in all these holes. It seems probable that south of sec. 15 the coal-bearing formation was eroded in a pre-Wasatch valley before the deposition of the Wasatch formation. The depth of the coal below the surface does not, in all probability, exceed a few hundred feet. If the structure of the coal-bearing formation in general conforms to the less marked structure of the overlying Wasatch, it is probable that the coal outcrop swings somewhat to the west to conform to the strike of the Wasatch beds in the SW. $\frac{1}{4}$ sec. 22. The strike of these beds conforms to that of the coal-bearing formation exposed in Spring Canyon, and this makes it more probable that the strike of the coal bed in this locality follows the same direction. In that case the concealed outcrop of the "Wasatch" coal would underlie the valley of the Weber somewhere near the site of the little town of Hoytsville. If, however, an extensive fault which is concealed by the overlying mantle of Wasatch strata has broken the outcrop of the coal south of the area in which surface exposures occur, it is of course impossible to make any predictions concerning the probable location of the coal bed.

Dry Hollow bed.—The Dry Hollow bed has been prospected in the NW. $\frac{1}{4}$ sec. 4, near the township line. A quarter of a mile southwest of this place the bed is broken by a fault which is apparent in the overlying sandstone, the outcrop of the coal being obscured. Near the middle of sec. 5 the bed is broken by a second fault having a downthrow on the north, as shown by the relation of the sandstone ledges, the coal itself not being exposed. Two small faults break the bed in the NW. $\frac{1}{4}$ sec. 8, the downthrow in each being to the

north. The coal bed has been prospected in the SW. $\frac{1}{4}$ sec. 8 but is entirely concealed between this place and the exposures in Dry Hollow. The coal has also been opened at the Sargent mine, in the SE. $\frac{1}{4}$ SE. $\frac{1}{4}$ sec. 18, where it is reported by one of the owners to be 31 inches thick and to be overlain by 2 feet of black shale with sandstone above. A report is current in Coalville to the effect that the Dry Hollow bed wherever it has been opened consists of two benches separated by 18 inches of shale. The Sargent mine was so caved at the time of the examination that an exact measurement could not be obtained. The correlation of the coal at the Sargent mine with the Dry Hollow bed is somewhat doubtful, because of the increased thickness of shale between the coal and the prominent sandstone ledge, the top of which, at the Sargent mine, is 450 feet above the coal. In Dry Hollow and on Grass Creek the top of this sandstone is only about 280 feet above the Dry Hollow coal. Mr. Stanton is of the opinion, from the fossil evidence, that the two coal beds occupy approximately the same horizon, and it seems more reasonable to assume that the beds at the Sargent mine and in Dry Hollow are the same, the difference in thickness of the overlying strata being due to differences in deposition in waters adjacent to the shore of a considerable land mass rather than to assume that there are two distinct coal lenses. In this connection it may be noted that the thickness of the shale between the coal at the Sargent mine and the conglomerate doubtfully correlated with that of No. 7 (see p. 177) as exposed on Grass Creek is 1,300 feet (see p. 163), as compared with 880 feet on Grass Creek. It is possible that all the shale members of the section are thicker toward the west.

One mile south of the Sargent mine the Dry Hollow coal has been opened at what is known as the old Carleton mine, one of the oldest mines in the field and long since abandoned. The section of the bed is reported to be as follows:

Section of Dry Hollow coal at Carleton mine.

	Feet.
Sandstone roof.	
Coal.....	1
Shale.....	1
Coal.....	3

The coal is not exposed south of the Carleton mine. The overlying sandstone can be traced for about a quarter of a mile to a valley which crosses the outcrop at this point. South of the valley the surface rocks consist of the conglomerate of the Wasatch formation. It has been believed by some observers that the coal-bearing beds are here cut off by a fault which crosses the outcrop almost at right angles, and this belief is to some extent borne out by the dip in the Wasatch beds south of the valley. (See p. 170.) The existing conditions can be adequately accounted for, however, by the presence

of a pre-Wasatch valley eroded in the coal and the overlying sandstone, the valley being afterwards filled by Wasatch deposits.

Spring Canyon bed.—In the NW. $\frac{1}{4}$ sec. 26 two coal beds of rather doubtful value have been prospected on the north side of Spring Canyon. (See Pl. IX, A.) At 100 feet below the lowest bed is a white sandstone about 35 feet thick, which forms a prominent escarpment on each side of the valley. The strike is N. 30° E. and the dip 26° NW. About 18 feet below the base of this sandstone a bed of carbonaceous shale has been prospected, apparently without results. The section of the two coal beds 100 feet above the sandstone is as follows:

Section of coal beds in Spring Canyon.

	Ft.	in.
Coal, broken by several thin partings of shale.....	3	6
Shale.....	25	0
Coal.....	1	0
Shale.....		2
Coal.....		6
Shale.....		$\frac{1}{2}$
Coal.....	1	$5\frac{1}{2}$
Shale.....		2
Coal.....	1	2

These beds are said to have been opened by the Buell & Bateman Co., but the coal was too dirty to compete with that of the Wasatch bed. The outcrop of these two beds, together with that of the underlying sandstone, is concealed both north and south of Spring Canyon by the cover of Wasatch deposits. The exact position of these coal beds with reference to the Wasatch bed is unknown. They are apparently a considerable distance below it and are rather doubtfully correlated with two beds which have been prospected on the north side of Chalk Creek, in the NW. $\frac{1}{4}$ sec. 11 and the SW. $\frac{1}{4}$ sec. 1. The beds at the last-named locality lie about 50 feet above a cliff-forming sandstone, and the several thin beds which constitute the coal group are distributed through a thickness of about 75 feet of carbonaceous shale. A good measurement of the beds could not be obtained, but the thickest probably contains about 2 feet of rather bony coal. The underlying sandstone ledge may be traced northeastward across sec. 1 and thence eastward across the crest of the anticline to the SW. $\frac{1}{4}$ sec. 32, T. 3 N., R. 6 E., where a showing of coal appears above it at the crest of a hill. (See Pl. VIII, A.) The outcrop of the sandstone over part of this distance is rather obscured and the tracing difficult. From the SW. $\frac{1}{4}$ sec. 32 the bed may be traced southward across the western part of sec. 5, T. 2 N., R. 6 E., where it dips 90° on the vertical eastern limb of the anticline. From a measurement between the sandstone and the coal of the Wasatch bed, exposed at the Hoffman mine in the SW. $\frac{1}{4}$ sec. 5, it appears that the coal group is approximately 850 feet below the



4. VIEW LOOKING WEST DOWN SPRING CANYON, UTAH.

Prospects on coal bed (No. 15 (?) of section, p. 163) in foreground on right, Weber Valley and escarpment of sandstone (No. 4 of section) in middle distance.



B. VIEW LOOKING NORTH UP HUFF CREEK IN SEC. 13, T. 3 N., R. 6 E., UTAH.

Sandstone (No. 4 of section, p. 163) on right. (See p. 182.)



A. VIEW NEAR BOYER MINE, SEC. 36, T. 3 N., R. 6 E., UTAH.

Looking northeast. Sandstone (No. 11 of section, p. 163) overlying coal bed.



B. HOFFMAN MINE, SEC. 5, T. 2 N., R. 6 E., UTAH.

"Wasatch" coal bed (No. 12 of section, p. 163), 10 feet thick, dips 78° W. on limb of overturned anticline. Sandstone floor on left, shale roof on right.

Wasatch bed. As stated above, the tracing of the sandstone ledge across the crest of the anticline is by no means positive. Should a strike fault exist near the crest or on the eastern limb of the incline, it would be very difficult to detect. It is believed, however, that the relations of the beds have been correctly determined. Fossils collected near the coal group in the SW. $\frac{1}{4}$ sec. 1, T. 2 N., R. 5 E., have been discussed on page 165.

T. 3 N., R. 6 E.

"Wasatch" coal bed.—The *"Wasatch"* bed is worked at the Union Fuel Co.'s mine, in the SW. $\frac{1}{4}$ sec. 18, T. 3 N., R. 6 E. Considerable faulting has been encountered in the mine and the coal has apparently been affected by slipping along the bed. Its thickness ranges from 5 to 13 feet. The strike of the bed changes rather abruptly east of this mine, taking a direction of S. 50° E.

A quarter of a mile southeast of the mine of the Union Fuel Co. is the opening of the old Church mine, from which a large amount of coal was taken some 40 years ago. Southeast of this mine the outcrop of the coal and of the conglomeratic sandstone which immediately overlies it is concealed across the crest of the Grass Creek and Chalk Creek divide. A little over half a mile southeast of the old Church mine is a small sandstone knob, which is probably formed by either the sandstone bed which underlies the coal or that which overlies it. From this place across the divide for three-quarters of a mile there is no exposure of the coal-bearing formation, but in the NW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 21 the sandstone ledge which underlies the coal appears at the surface, dipping 8° NE. The ledge may be traced for a quarter of a mile southeastward, where in the SW. $\frac{1}{4}$ SW. $\frac{1}{4}$ sec. 21 the coal bed just above it has been prospected. The strike is here N. 31° W. and the dip 25° NE. One thousand feet to the southeast the coal is also exposed, the strike changing abruptly to S. 35° W. (See Pl. VII, A.) The bed may be traced for a quarter of a mile to the southwest and has been opened in three different places with a reported thickness of 11 feet. The bed here dips 70° SE., but the dip increases rapidly to the southwest until the beds are vertical. For $2\frac{1}{2}$ miles southwest of these prospects, to the openings in the SW. $\frac{1}{4}$ sec. 5, T. 2 N., R. 6 E., the coal is concealed, and the location of the bed can be determined only from its relation to the overlying sandstones, which are exposed east of it. Only an approximate estimate can be made of the depth below the surface, reached by the coal bed along the axis of the syncline, which lies west of the anticline above described. It is probably about 6,500 feet. For 1 mile east of the coal outcrop the overlying beds are vertical, but farther eastward they rise gradually at angles of 16° to 21°. The axis of the syncline is apparently a very sharp fold, the dip at the surface changing in a few rods from 90° to 14° W. Whether or not there is faulting along the axis of the

syncline it is impossible to tell from surface exposures. If faulting exists, it is probably not great, as what are taken to be the same sandstone ledges appear within a few rods on each side of the synclinal axis. From the axis of the syncline the beds rise steadily toward the east for a little over 3 miles, the "Wasatch" coal bed appearing at the surface in the NE. $\frac{1}{4}$ NE. $\frac{1}{4}$ sec. 36, at what is known as the Boyer mine. This mine is not worked at present, but the coal is reported to be 8 feet in thickness. About 22 feet above it is the base of a sandstone 130 feet thick, which forms a prominent ridge on the north side of Chalk Creek. (See Pl. X, A.) The dip is here 12° W. and the strike north. On the crest of the hill north of this place the coal-bearing rocks are entirely concealed by the cover of Wasatch deposits, and, so far as known, the coal does not appear at the surface for a distance of 4 miles to the north. In the NE. $\frac{1}{4}$ sec. 13, however, a bed of coal reported to be 5 feet thick was formerly worked at an old mine near a spring on the west side of the Huff Creek road. This coal is 470 feet stratigraphically below the base of a prominent sandstone ledge and is possibly the "Wasatch" bed, but this correlation is by no means positive.

Dry Hollow bed.—In the NE. $\frac{1}{4}$ sec. 13, T. 3 N., R. 6 E., about 2 feet of coal is exposed on the north side of a draw. Above the coal is a bed 20 feet thick composed of oyster shells. These shells were formerly burned for lime, and the ruins of the old kiln are still standing. Specimens of these oysters were examined by T. W. Stanton, who states that they are a species usually associated with the Dry Hollow coal. Above the shell bed is a 10-foot bed of sandstone, and above that several hundred feet of shale, overlying which are two sandstone ledges separated by shale or soft sandstone. The two ledges together are perhaps 200 or 250 feet thick. On the surface of the upper ledge (Pl. IX, B) were found specimens of *Inoceramus*, believed to be *Inoceramus erectus*, a species which in this field is characteristic of the sandstone above the Dry Hollow coal. On the evidence of this *Inoceramus* and the species of oyster, the coal associated with the shell bed is provisionally correlated with the Dry Hollow coal. The outcrop of the "Wasatch" bed (No. 12) should come to the surface about a mile to the east but is probably concealed by the strata of the Tertiary conglomerate. If the old mine in the NE. $\frac{1}{4}$ sec. 12 is on the "Wasatch" bed there must be either a sharp fold or a fault between it and the outcrop of the coal and shell bed just described. There is some evidence of such a fault near the north line of sec. 13. Opportunity was not afforded for more than a hasty examination of this locality.

In the SE. $\frac{1}{4}$ sec. 16 a bed of coal reported to be from 18 to 24 inches thick outcrops between two sandstone ledges, the upper of which is 40 feet thick and has embedded in its upper surface great numbers of

large shells of *Ostrea soleniscus*. Below the coal is about 100 feet of soft sandstone, and below that a second ridge-forming sandstone. These sandstone beds appear to be the same as those which appear near Coalville above the Dry Hollow coal. The coal just described as occurring between the two sandstone ledges is probably a somewhat higher bed than the Dry Hollow. Its outcrop was not observed at any other locality, though coal is reported at about the same horizon in what is known as the Middle Canyon, $2\frac{1}{2}$ miles to the southwest.

T. 2 N., R. 6 E.

"Wasatch" coal bed.—The "Wasatch" bed has been opened in two places in the SW. $\frac{1}{4}$ sec. 5, T. 2 N., R. 6 E., at what are known as the Hoffman mines, which are worked only to supply local demand. One of these mines is now on fire. The coal here occurs on the steeply dipping limb of the anticline, which appears to be slightly overturned, the strata dipping 78° W. (See Pl. X, B.) The bed is 10 feet thick, but contains several small lenses of shale which apparently represent a shale parting in the bed, the shale having been formed into lenses by the compression to which the bed has been subjected. Half a mile south of the Hoffman mine the coal is exposed on the east face of the hill just north of the Chalk Creek road, in the NW. $\frac{1}{4}$ sec. 8. Below the bed is a sandstone ledge 79 feet thick, which forms the abrupt cliff known as Halfway Rock, on the north side of the road. It is reported that the "Wasatch" bed was opened just south of Chalk Creek, a few rods south of this locality. A low ridge of sandstone, which probably underlies the coal, may be observed trending in a direction a little west of south on the north slope of Elkhorn Mountain and extending to the SW. $\frac{1}{4}$ sec. 18, but south of this place the coal-bearing formation is concealed by the overlying Wasatch strata. An estimate of the depth of the "Wasatch" coal bed in the syncline, the axis of which lies a little over half a mile east of the outcrop of the bed, can be only approximate. If the structure is regular and can therefore be inferred from the surface outcrops, it is probable that the coal descends to a depth somewhat below sea level, or, in other words, 6,500 feet below its surface altitude in this township. If the overturn of the beds is more than a local feature of the structure and extends far below the surface, the axis of the syncline at the great depth which it attains must lie almost three-quarters of a mile west of the axis as it appears at the surface. Exposures of the pre-Wasatch rocks may be seen along South Fork of Chalk Creek for 2 miles above its mouth, but near the head of that stream all exposures are concealed by the strata of the overlying Wasatch.

No outcrops of the Spring Canyon or Dry Hollow coal beds were observed in T. 2 N., R. 6 E.

THE MAP.

Topography and geology.—The topography shown on the accompanying map was surveyed by H. L. Baldwin and Jeremiah Ahern in 1899 and 1900. The geologic mapping in Tps. 2 and 3 N., R. 6 E., was done directly on the topographic map, a plane table being used in obtaining locations. The geologic mapping in Tps. 2 and 3 N., R. 5 E., was done with a plane table and telescopic alidade independently of the former topographic mapping, the two maps being afterward combined in the office. In the work a base line 5,610 feet was measured from a point on the road near the schoolhouse just north of Coalville to a flag established near the east quarter corner of sec. 4, T. 2 N., R. 5 E. From this base line control was expanded over the township. Elevations were calculated by vertical-angle readings, the United States Geological Survey benchmark 5607 near the road just north of town being used as a starting point. All locations were made by triangulation, no traverse work being done. Control was carried over T. 3 N., R. 5 E., from a base line, the ends of which were the flag in the SE. $\frac{1}{4}$ sec. 34 and the sandstone point in the NW. $\frac{1}{4}$ sec. 5, these points having been established in the work on T. 2 N., R. 5 E.

Land lines.—The land lines as shown do not altogether agree with those as given on the topographic map. Section corners wherever found were located by triangulation, and the land lines were projected from the known corners according to the plats of the General Land Office. Where corners are shown on the map as found, the land lines may be considered as accurate in location. Where no corners were found, the lines are to be considered as more or less hypothetical. The original land survey of the area, part of which was made as early as 1869, appears to have been conscientiously made.

Structure contours.—The structure contours as given on the map are drawn on the principal or "Wasatch" coal bed and represent absolute elevations above sea level. They are drawn from actual elevations taken along the outcrop of the coal bed, from elevations taken on various sandstone ledges between which and the "Wasatch" bed the intervals were known, and from dip readings. Where outcrops are few, and consequently the data on which the structure contours are based are meager, the contours are to be understood as representing more the general structure of the region than the absolute depth at which the coal bed lies. The approximate depth of the "Wasatch" coal below the surface can be calculated at any point in the area by subtracting the elevation as given by the structure contour on the coal at that point from the surface elevation. The depth of the Dry Hollow coal bed can be easily calculated from this result, as the stratigraphic interval between the "Wasatch" bed and the Dry Hollow bed is 2,000 feet.

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